

Chapter 3

Mobile Radio Propagation

Outline

- Speed, Wavelength, Frequency
- Types of Waves
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- Propagation Mechanisms
- Radio Propagation Effects
- Free-Space Propagation
- Land Propagation
- Path Loss
- Fading: Slow Fading / Fast Fading
- Delay Spread
- Doppler Shift
- Co-Channel Interference
- The Near-Far Problem
- Digital Wireless Communication System
- Analog and Digital Signals
- Modulation Techniques

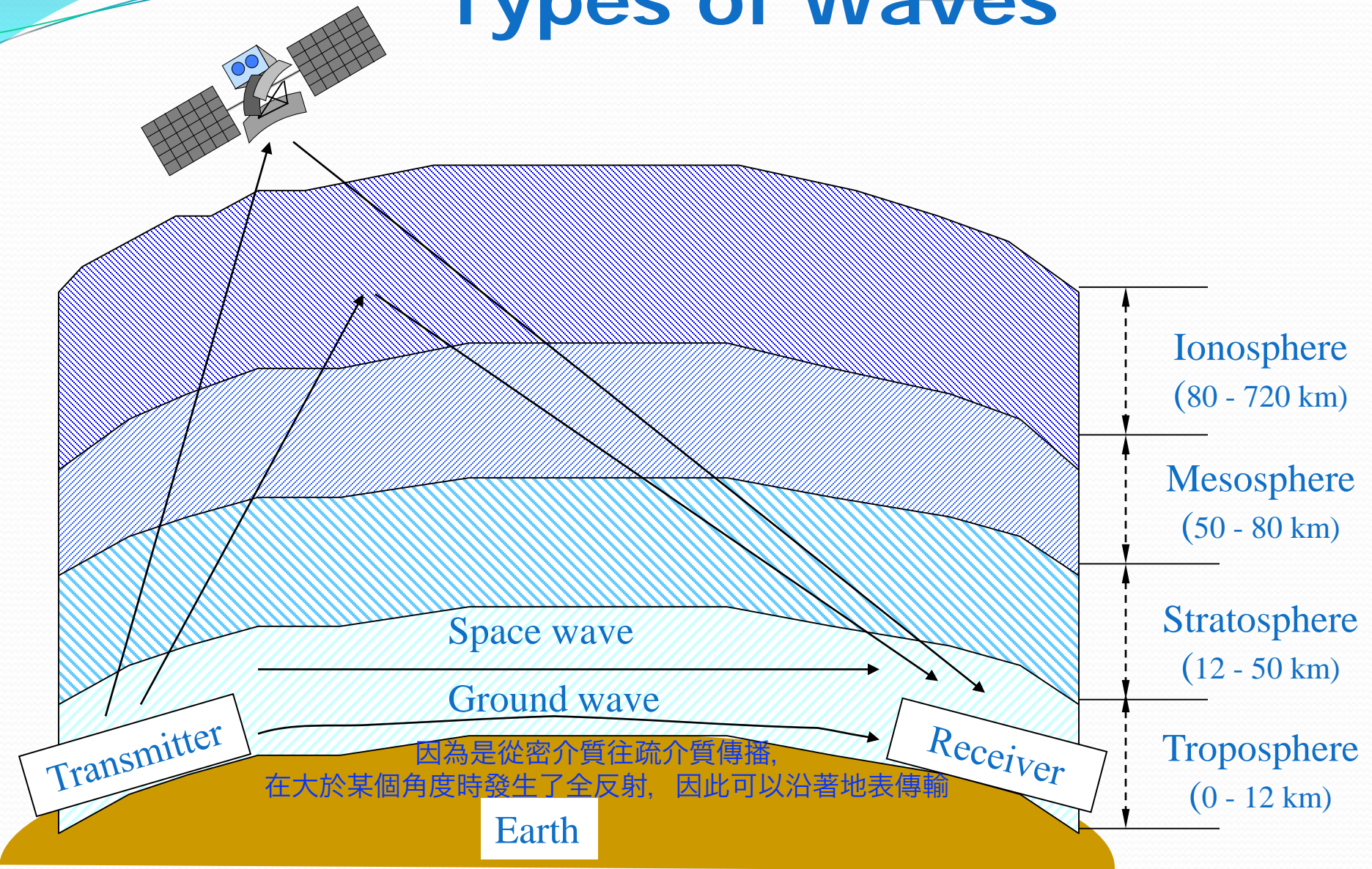
Speed, Wavelength, Frequency

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

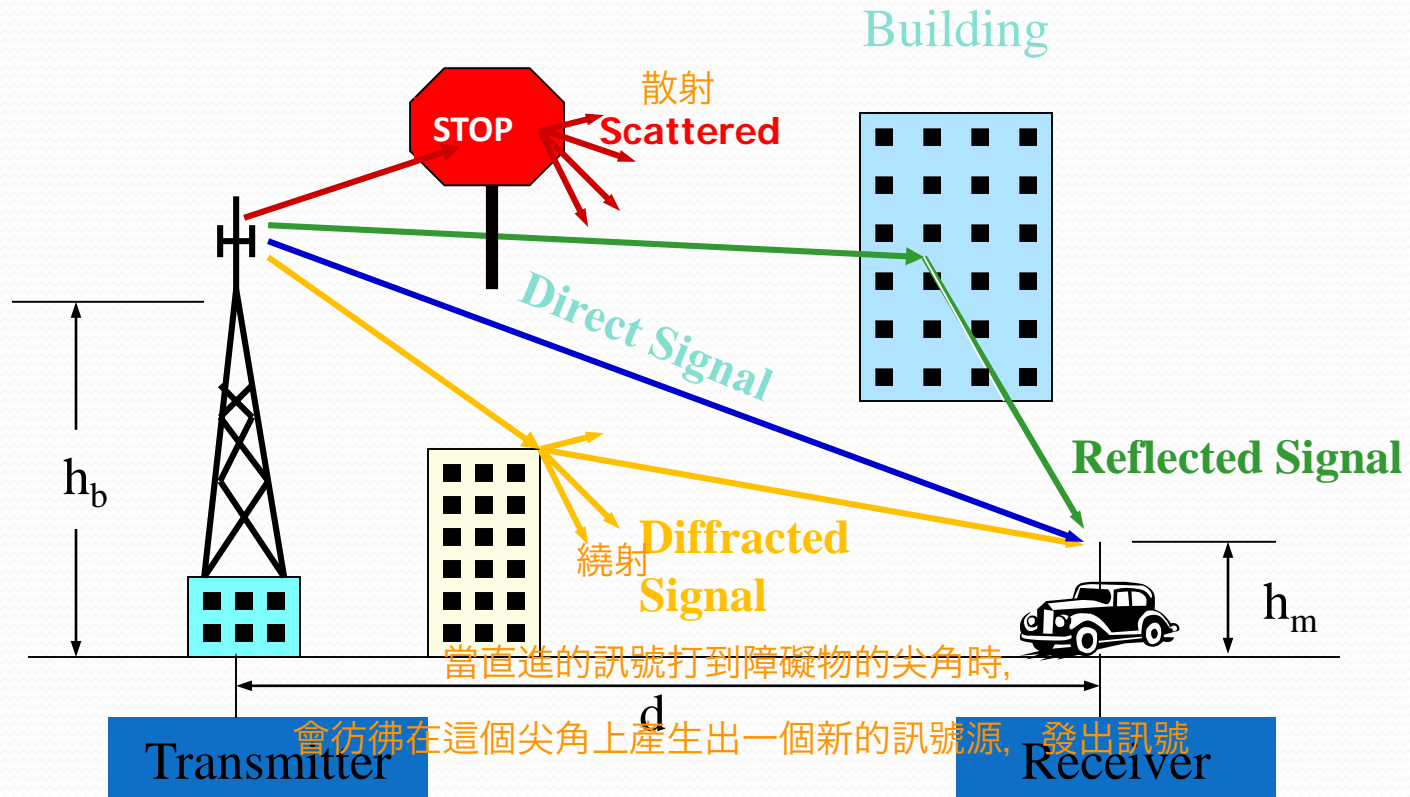
Classification Band	Initials	Frequency Range	Characteristics
Extremely low	ELF	< 300 Hz	Ground wave
Infra low	ILF	300 Hz - 3 kHz	
Very low	VLF	3 kHz - 30 kHz	
Low	LF	30 kHz - 300 kHz	
Medium	MF	300 kHz - 3 MHz	Ground/Shy wave
High	HF	3 MHz - 30 MHz	Sky wave
Very high	VHF	30 MHz - 300 MHz	Space wave
Ultra 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

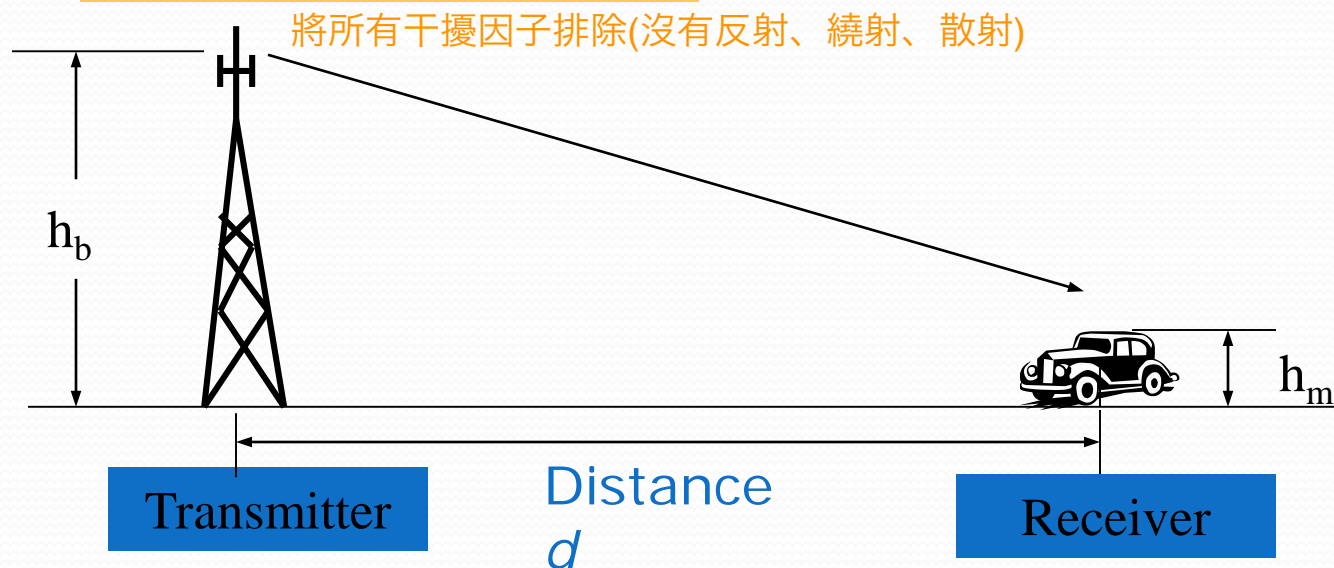
- Reflection
 - Propagation wave impinges on an object which is large as compared to wavelength
 - e.g., the surface of the Earth, buildings, walls, etc.
- Diffraction
 - Radio path between transmitter and receiver obstructed by surface with sharp irregular edges
 - Waves bend around the obstacle, even when **LOS** (line of sight) does not exist
- Scattering 當波行進間撞到跟波長大小差不多的物體
 - Objects smaller than the wavelength of the propagation wave
 - e.g. foliage, street signs, lamp posts

視線範圍

Radio Propagation Effects



Free-space Propagation



- The received signal power at distance d :

必考
$$P_r = \frac{A_e G_t P_t}{4\pi d^2} \quad P_r \propto d^{-2}$$

where P_t is transmitting power, A_e is effective area, and G_t is the transmitting antenna gain. Assuming that the radiated power is uniformly distributed over the surface of the sphere.

Antenna Gain

- For a circular reflector antenna

$$\text{Gain } G = \eta (\pi D / \lambda)^2$$

η = net efficiency (depends on the electric field distribution over the antenna aperture, losses, ohmic heating, typically 0.55)

D = diameter

thus, $G = \eta (\pi D f / c)^2$, $c = \lambda f$ (c is speed of light)

Example:

- Antenna with diameter = 2 m, frequency = 6 GHz, wavelength = 0.05 m

$$G = 39.4 \text{ dB}$$

- Frequency = 14 GHz, same diameter, wavelength = 0.021 m

$$G = 46.9 \text{ dB}$$

- * Higher the frequency, higher will be the gain for the same size antenna

Land Propagation

- The received signal power:

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

where P_r is the received power,

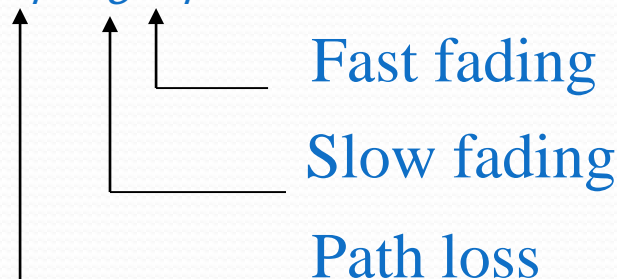
P_t is the transmitting power,

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 (Free-space)

- Path Loss: The signal strength decays exponentially with distance d between transmitter and receiver;

The loss could be proportional to somewhere between d^2 and d^4 depending on the environment.

- Definition of path loss L_P :

$$L_P = \frac{P_t}{P_r}, \quad \text{若是問strength 的話則是 } P_r/P_t$$

Path Loss in Free-space:

$$L_{PF}(dB) = 32.45 + 20\log_{10} f_c(MHz) + 20\log_{10} d(km),$$

where f_c is the carrier frequency.

→ This shows greater the f_c , more is the loss.

Path Loss (Land Propagation)

真實世界的情形

- Simplest Formula:

$$L_p = A d^\alpha$$

where

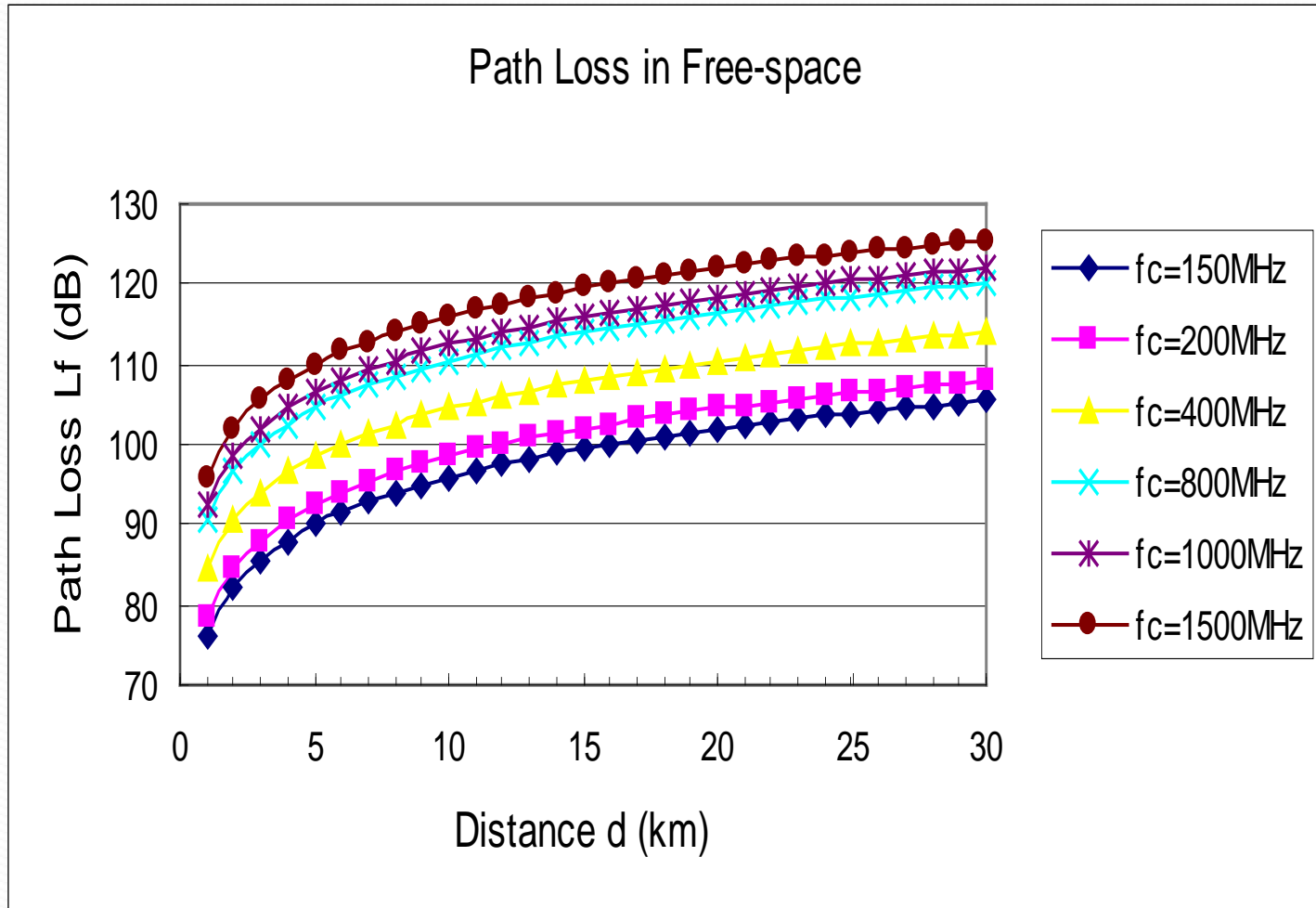
A and α : propagation constants

d : distance between transmitter and receiver

α : value of 3 ~ 4 in typical urban area

看實際上的環境對訊號影響的衰減程度會有所不同

Example of Path Loss (Free-space)



Path Loss

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

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

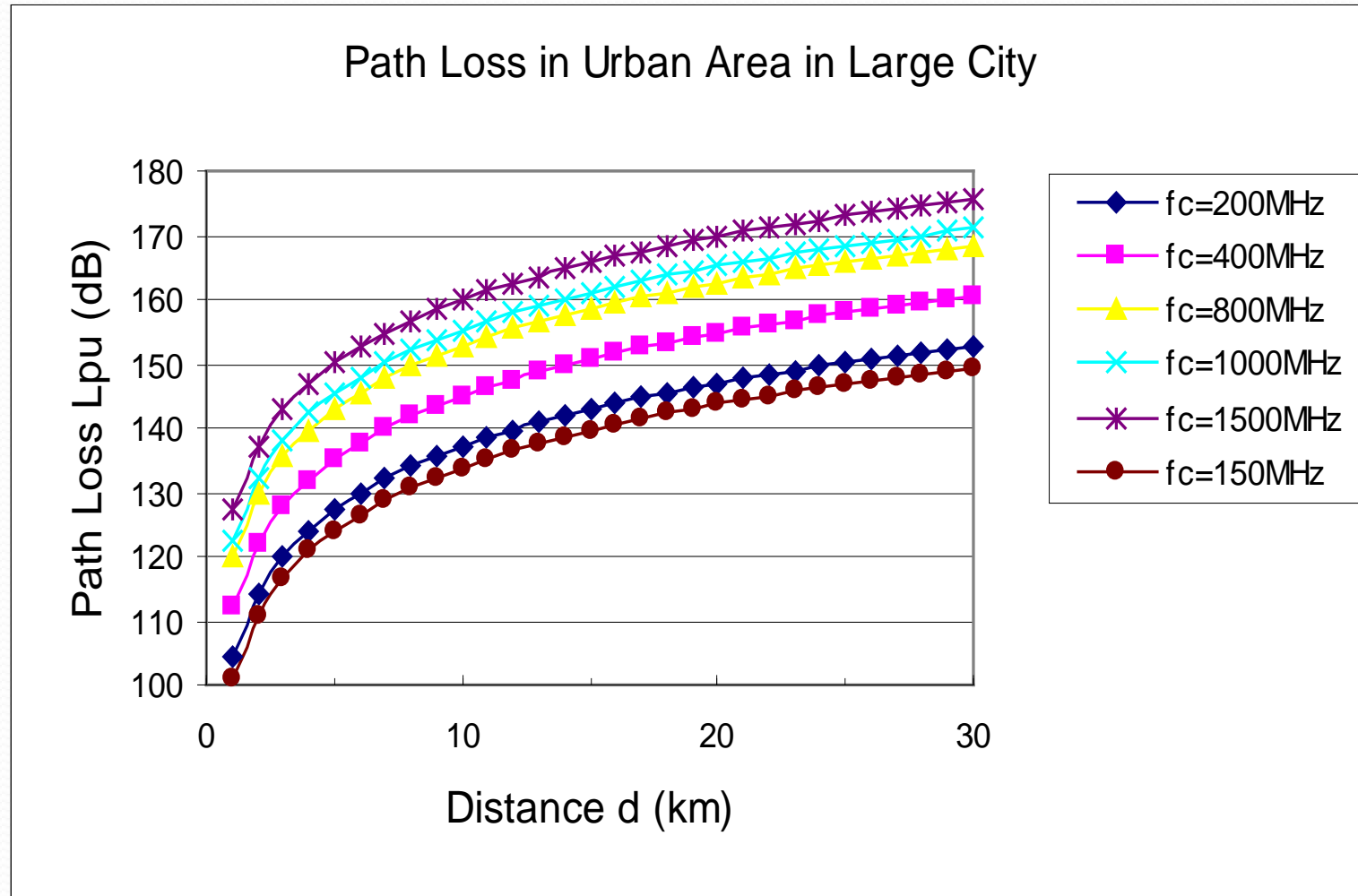
- Suburban area:

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

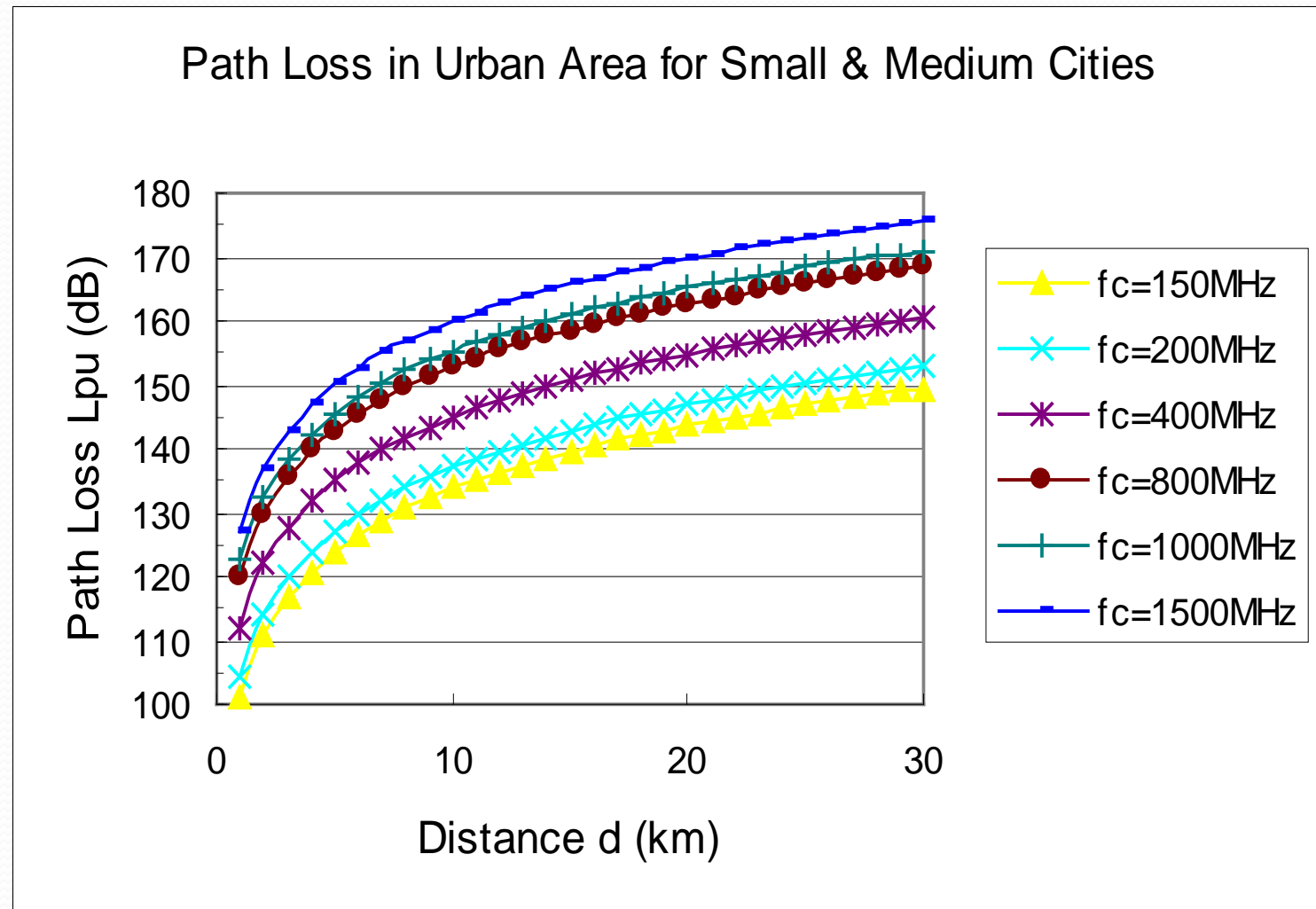
- Open area:

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

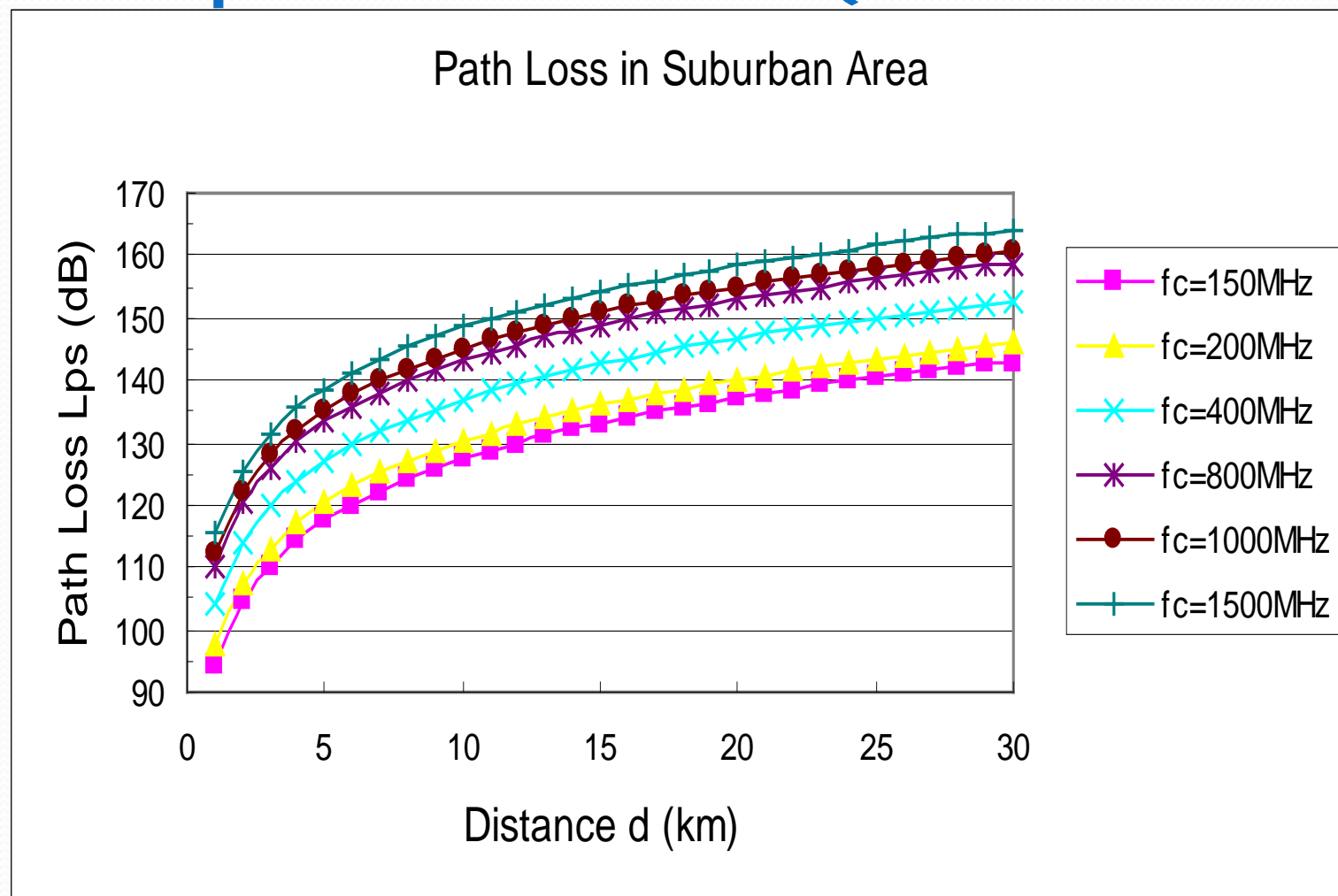
Example of Path Loss (Urban Area: Large City)



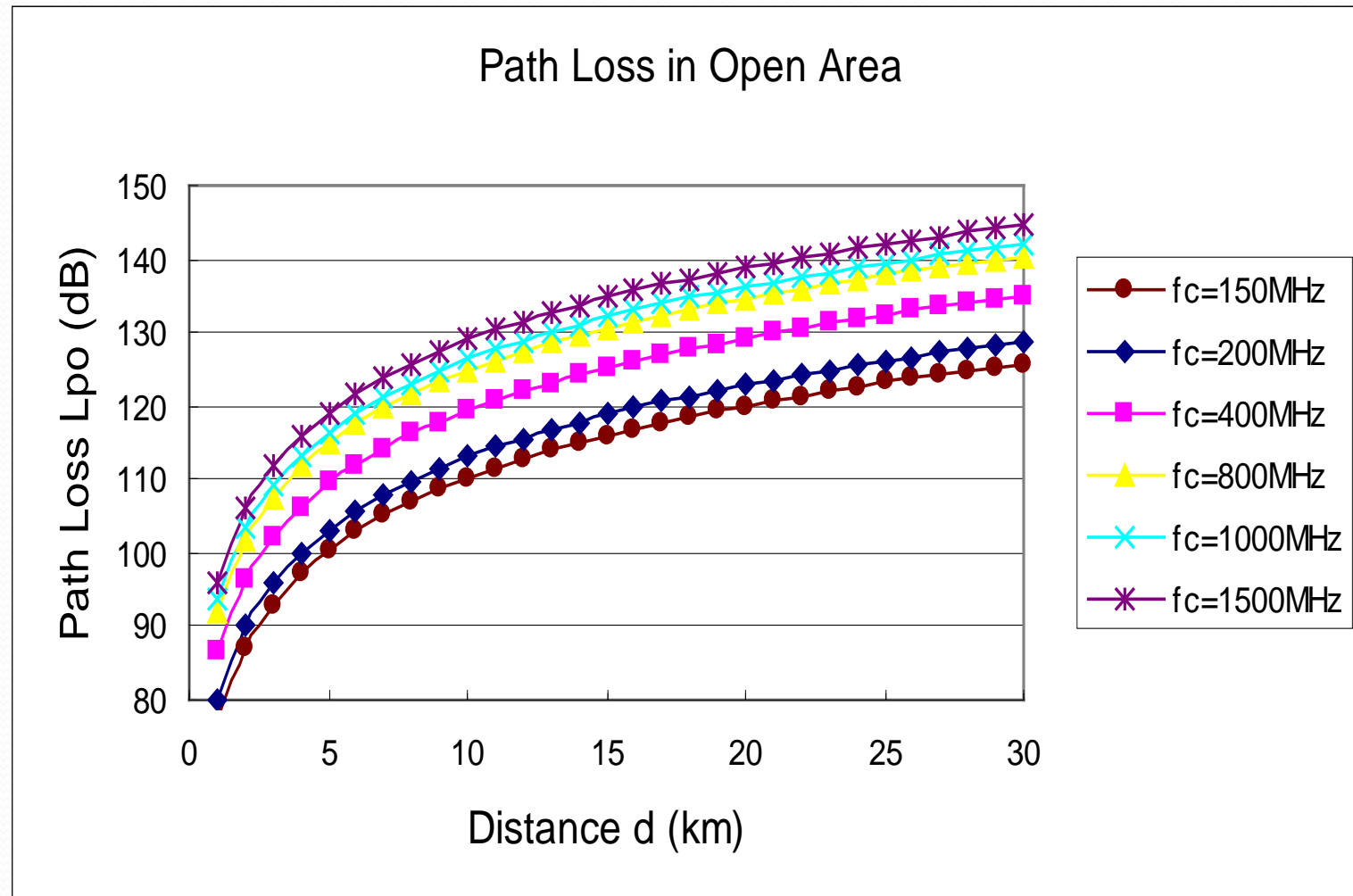
Example of Path Loss (Urban Area: Medium and Small Cities)



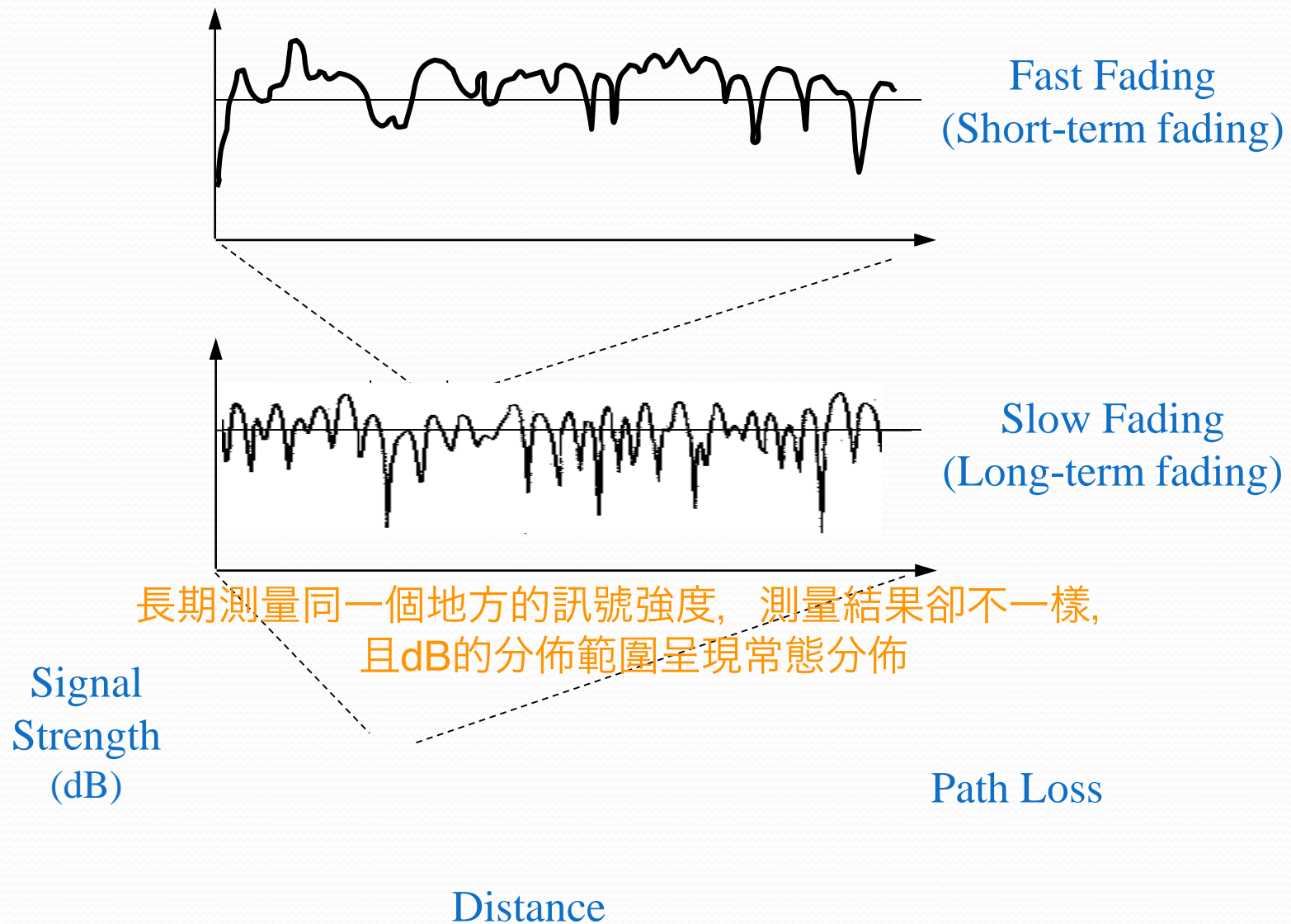
Example of Path Loss (Suburban Area)



Example of Path Loss (Open Area)



Fading 衰減



Slow Fading

例如傳輸途中中間有飛機飛過、有的傳輸路徑上有遮蔽物....受這些因素影響訊號傳輸

- Slow fading is caused by movement over distances large enough to produce gross variations in the overall path between transmitter and receiver.
- The long-term variation in the mean level is known as slow fading (shadowing or log-normal fading). This fading caused by shadowing.

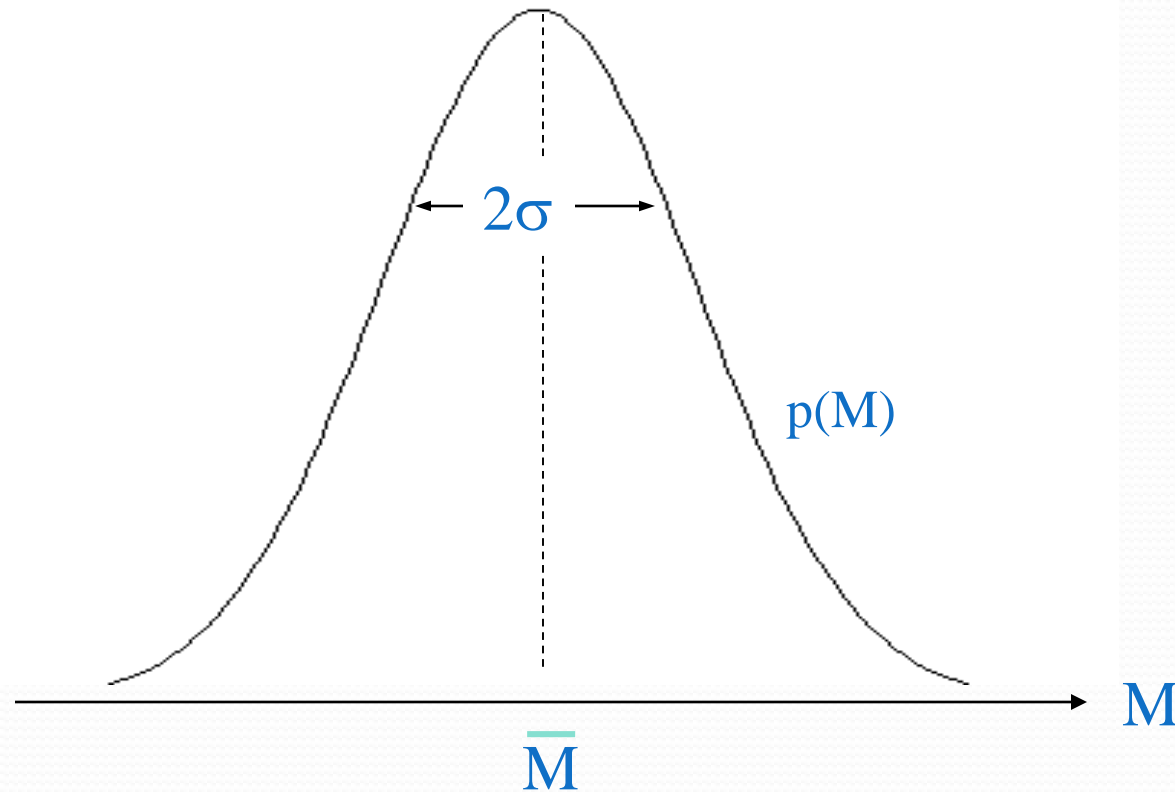
Shadowing

- **Shadowing**: Often there are millions of tiny obstructions in the channel, such as **water droplets** if it is raining or the individual **leaves** of trees. Because it is too cumbersome to take into account all the obstructions in the channel, these effects are typically lumped together into a random power loss.
- **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 mean of M ,
 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. Fast fading is due to **scattering** of the signal by object near transmitter.
 - When MS far from BS, the envelope distribution of received signal is Rayleigh distribution with $\beta=0$. The pdf is

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

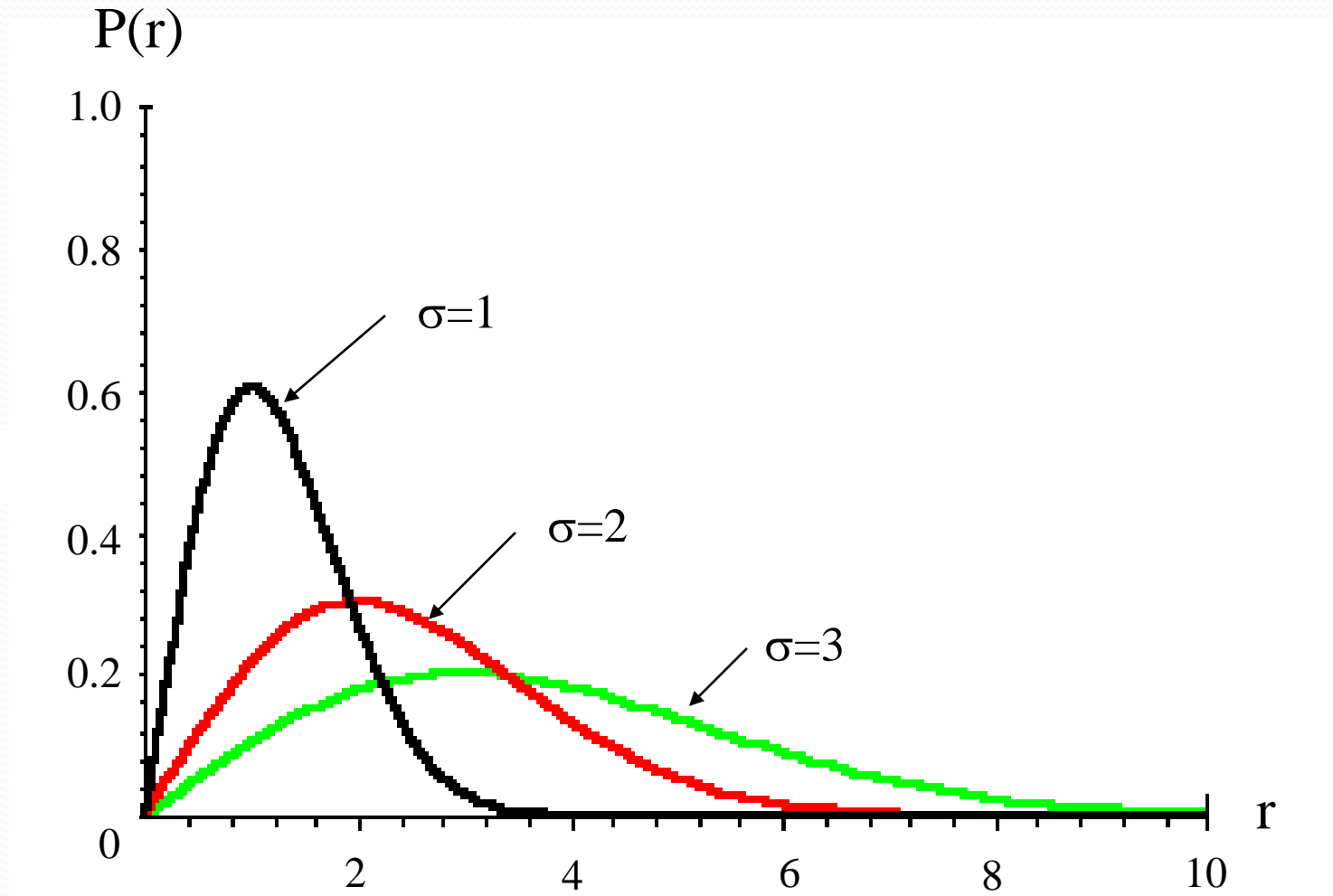
where σ is the standard deviation, r is the envelope of fading signal, β is the amplitude of direct signal, and I_0 is the zero order Bessel Function.

- Middle value r_m of envelope signal within sample range to be satisfied by

$$P(r \leq r_m) = 0.5.$$

- We have $r_m = 1.777$ ♦

Rayleigh Distribution



The pdf of the envelope variation

Fast Fading (Continued)

- When MS is far from BS, the envelope distribution of received signal is called a Rician distribution. The pdf is

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

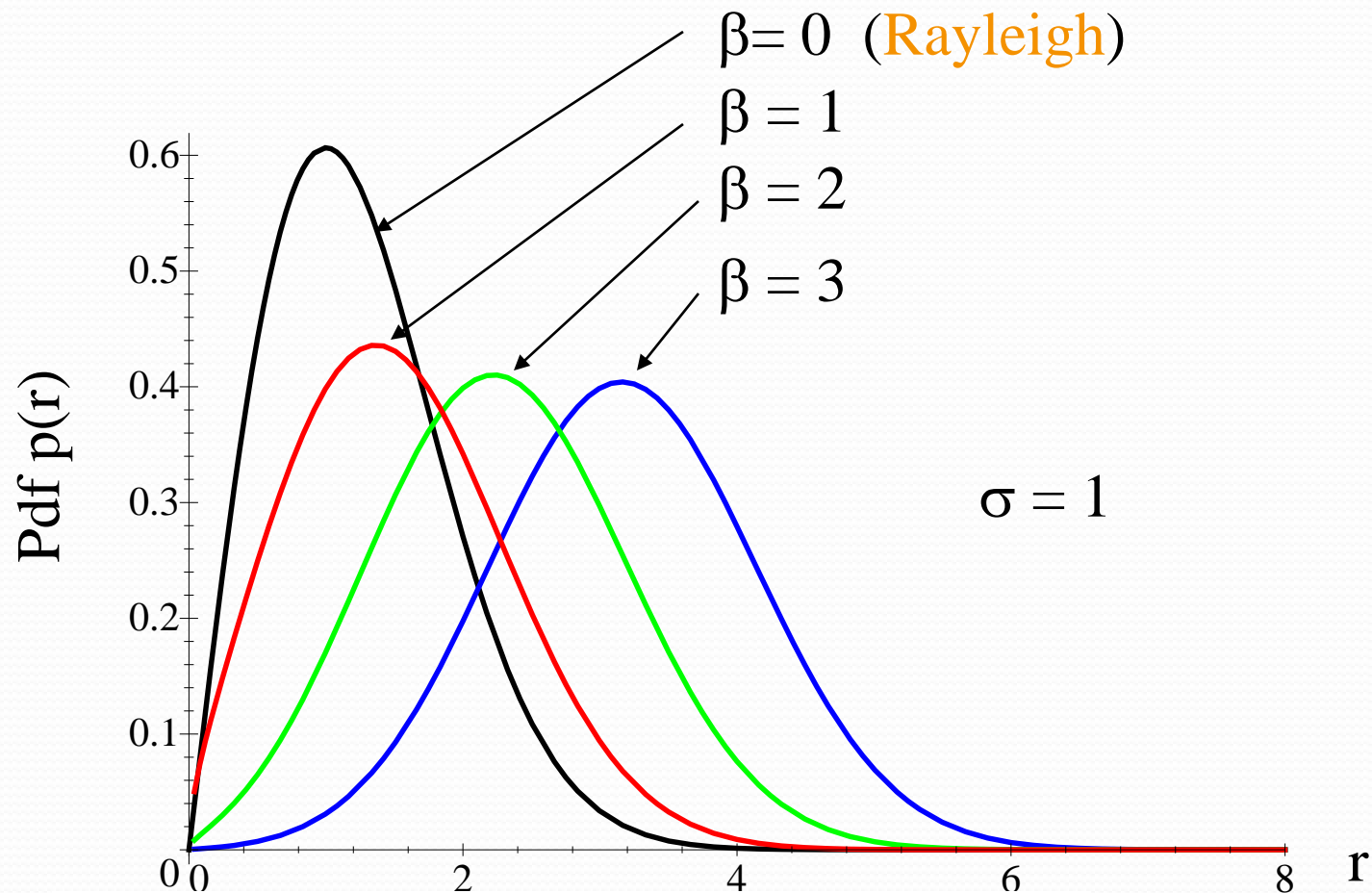
where

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

Rician Distribution



The pdf of the envelope variation

Characteristics of Instantaneous Amplitude

- Level Crossing Rate:
 - Average number of times per **second** that the signal envelope crosses the level in positive going direction.
- Fading Rate:
 - Number of times signal envelope crosses middle value in positive going direction per **unit** time.
- Depth of Fading:
 - Ratio of **mean** square value and **minimum** value of fading signal.
- Fading Duration:
 - Time for which signal is **below** given threshold.

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

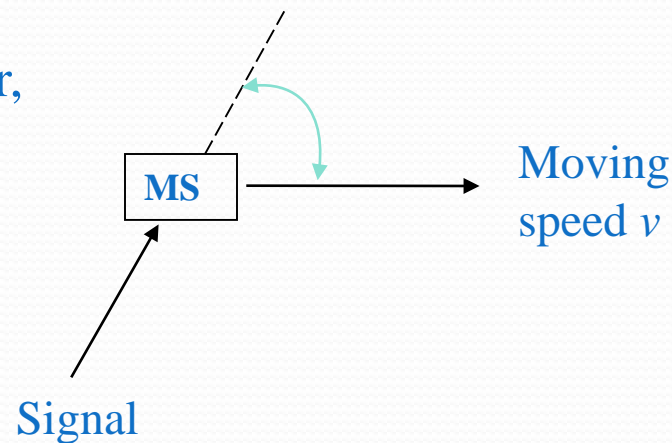
$$f_R = f_C - f_D$$

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

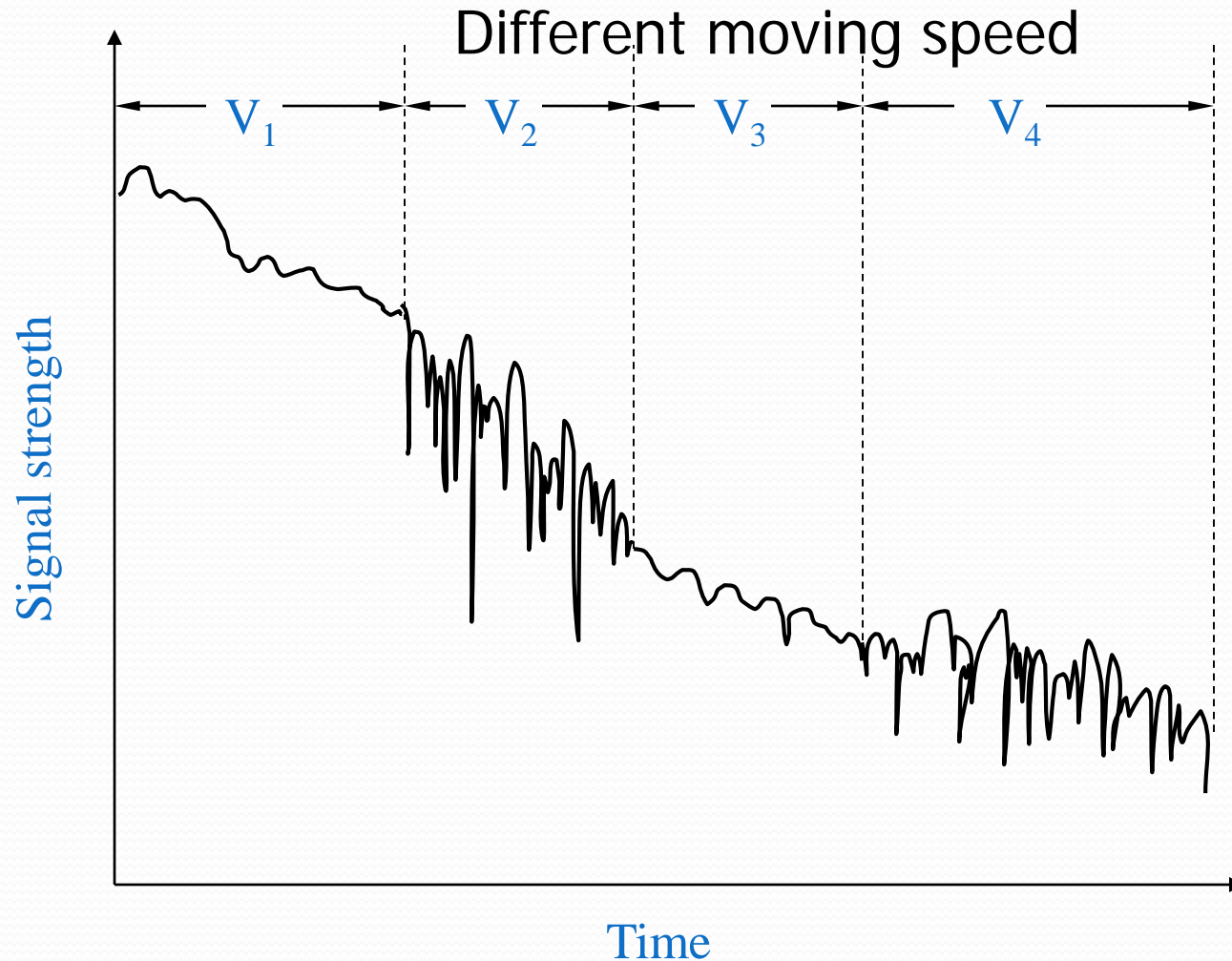
- **Doppler Shift** in frequency:

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

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



Moving Speed Effect



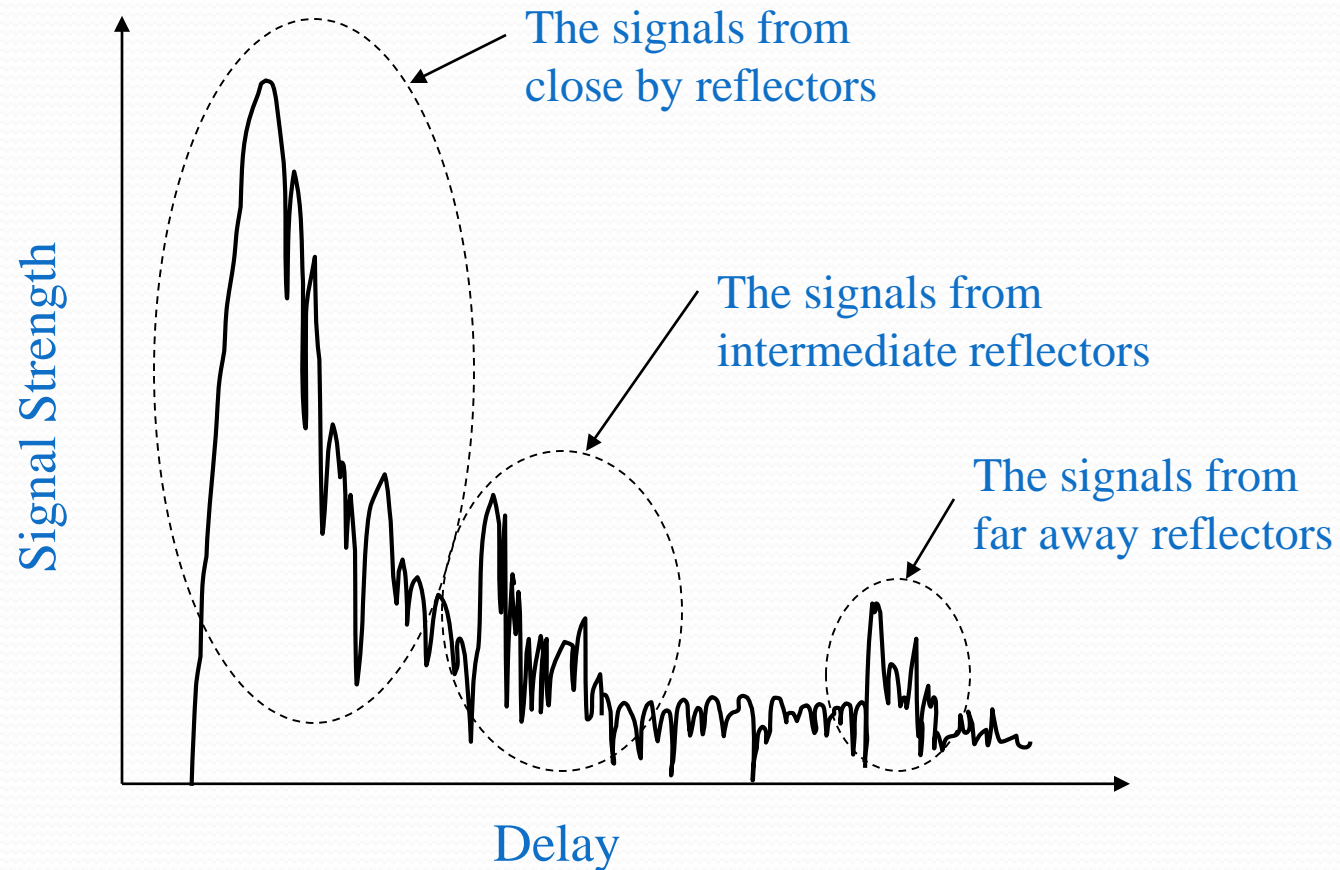
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Delay Spread

- 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”.

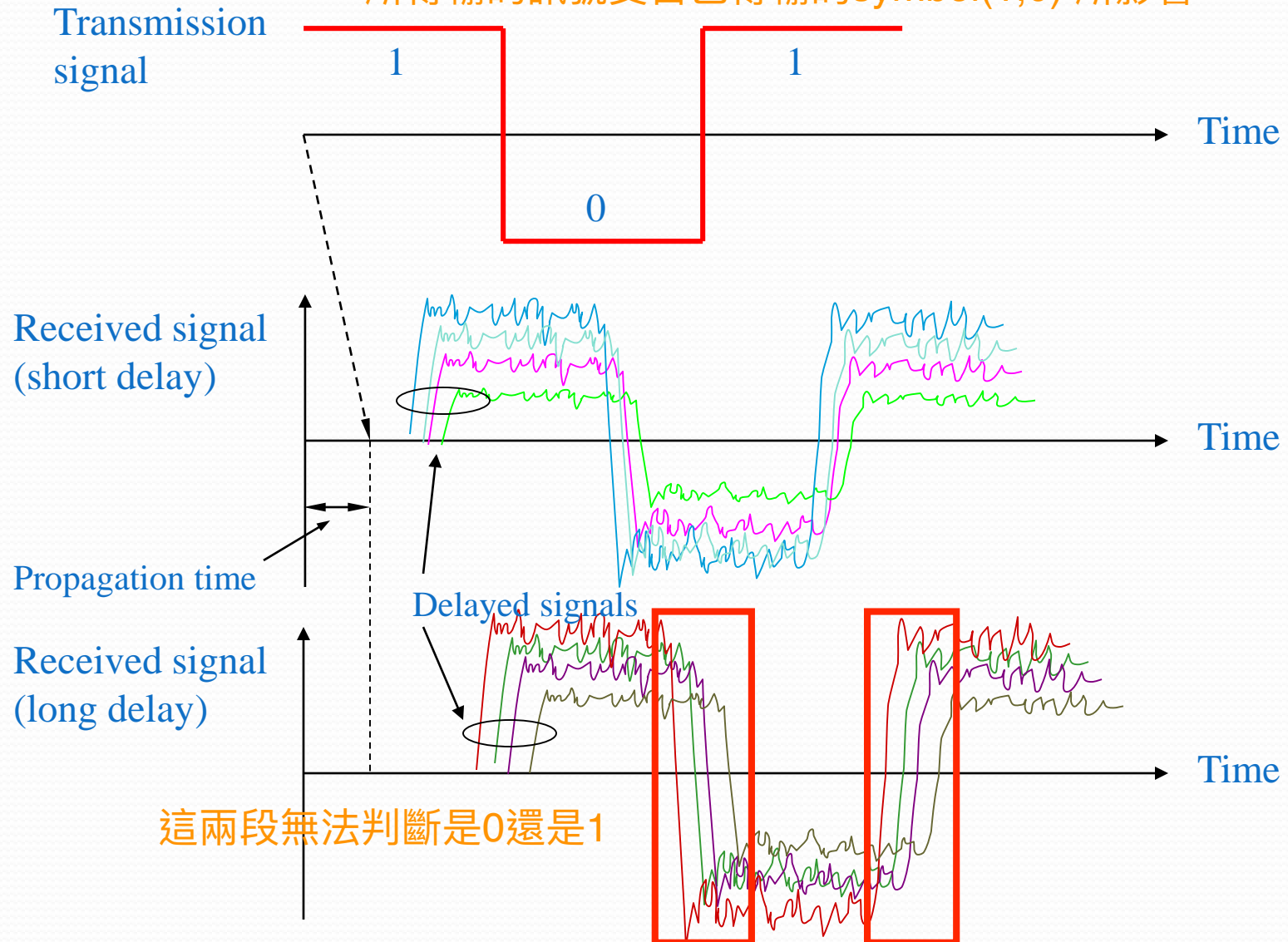
multi-path effect : 同一訊號透過不同的路徑(散射、繞射、反射...)傳到接收端

Delay Spread



Inter-Symbol Interference (ISI)

所傳輸的訊號受自己傳輸的symbol(1,0) 所影響



Inter-Symbol Interference (ISI)

- Caused by time delayed multipath signals
- Has impact on the burst error rate of channel
- Second multipath is delayed and is received during next symbol
- For low bit-error-rate (BER)

$$R < \frac{1}{2\tau_d}$$

- R (digital transmission rate) limited by delay spread
 τ_d • Delay spread 受先天上傳輸環境的影響

Coherence Bandwidth

- Coherence bandwidth B_c :
 - Represents correlation between two fading signal envelopes at frequencies f_1 and f_2 .
 - Is a function of delay spread.
 - 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

- Cells having the same frequency interfere with each other.
- r_d is the desired signal
- r_u is the interfering undesired signal
- β is the protection ratio for which $r_d \leq \beta r_u$
(so that the signals interfere the least)
- If $P(r_d \leq \beta r_u)$ is the probability that $r_d \leq \beta r_u$,
Cochannel probability $P_{co} = P(r_d \leq \beta r_u)$