

# RADIO PROPAGATION



**Propagation Ways**



**Propagation Models**



**Path Loss Calculation**

# What is propagation?



How radio waves travel between two points.

They generally do this in four ways:

- Directly from one point to another
- Following the curvature of the earth
- Becoming trapped in the atmosphere and traveling longer distances
- Refracting off the ionosphere back to earth.



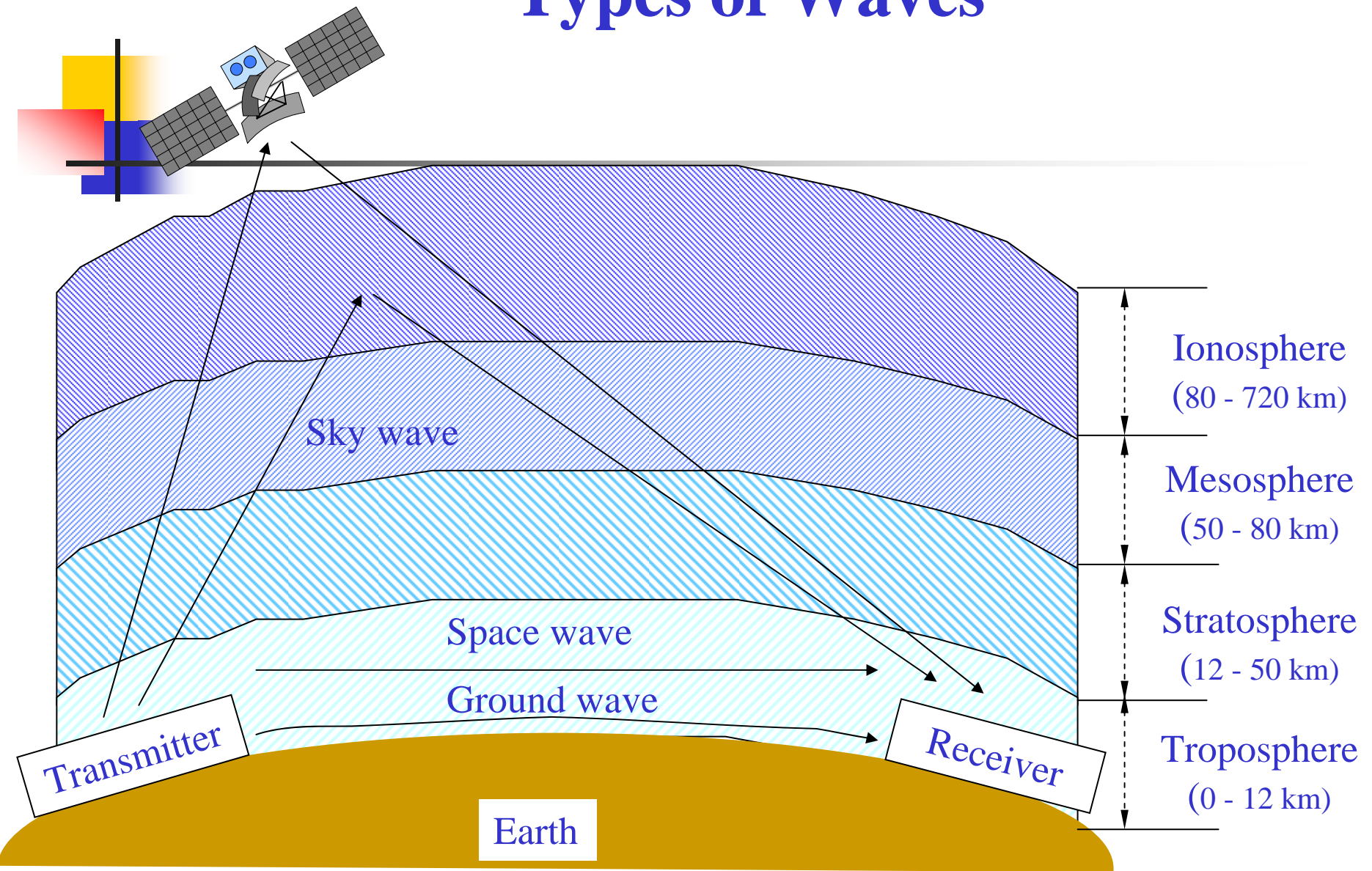
# Speed, Wavelength, Frequency

Light speed = Wavelength x Frequency

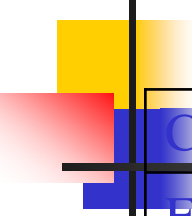
$$= 3 \times 10^8 \text{ m/s} = 300,000 \text{ km/s}$$

System	Frequency	Wavelength
AC current	60 Hz	5,000 km
FM radio	100 MHz	3 m
Cellular	900 MHz	33.3 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/Sky 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

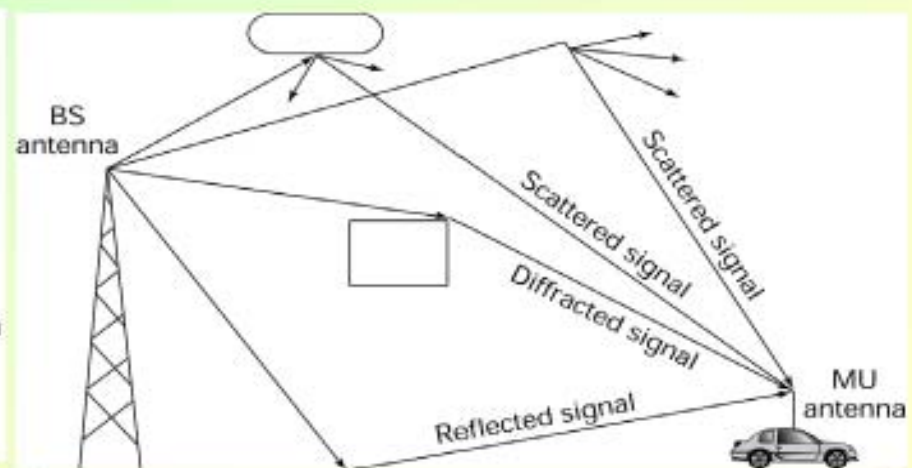
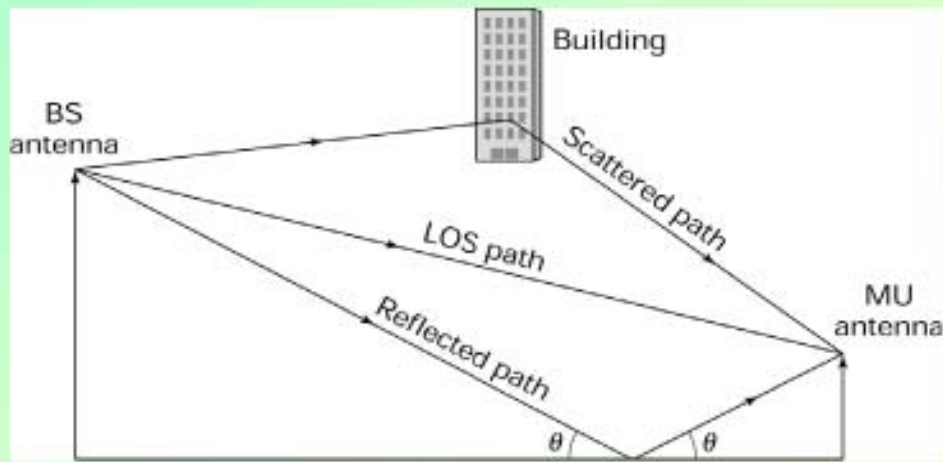
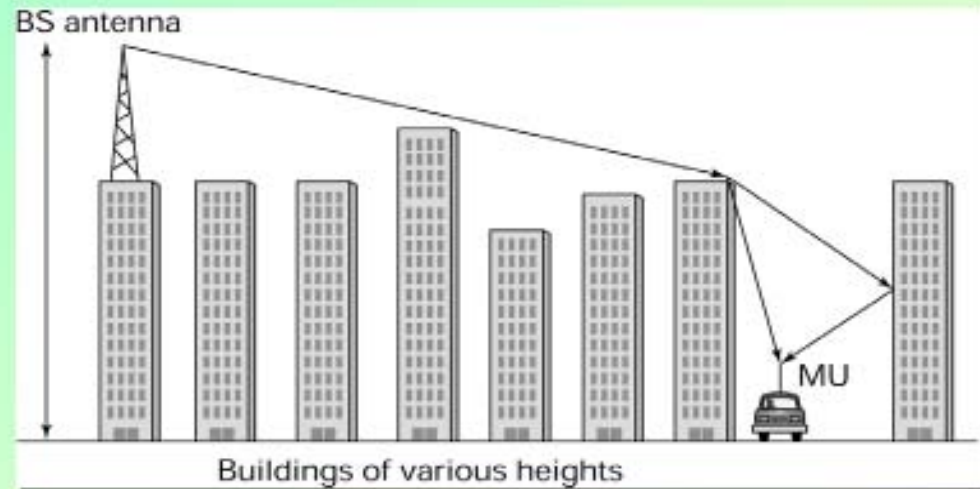
- Radio path between transmitter and receiver obstructed by surface with sharp irregular edges
- Waves bend around the obstacle, even when LOS (line of sight) does not exist

## ■ Scattering

- Objects smaller than the wavelength of the propagation wave
  - e.g. foliage, street signs, lamp posts

# Propagation Model - Mechanisms

- Reflection
- Diffraction
- Scattering





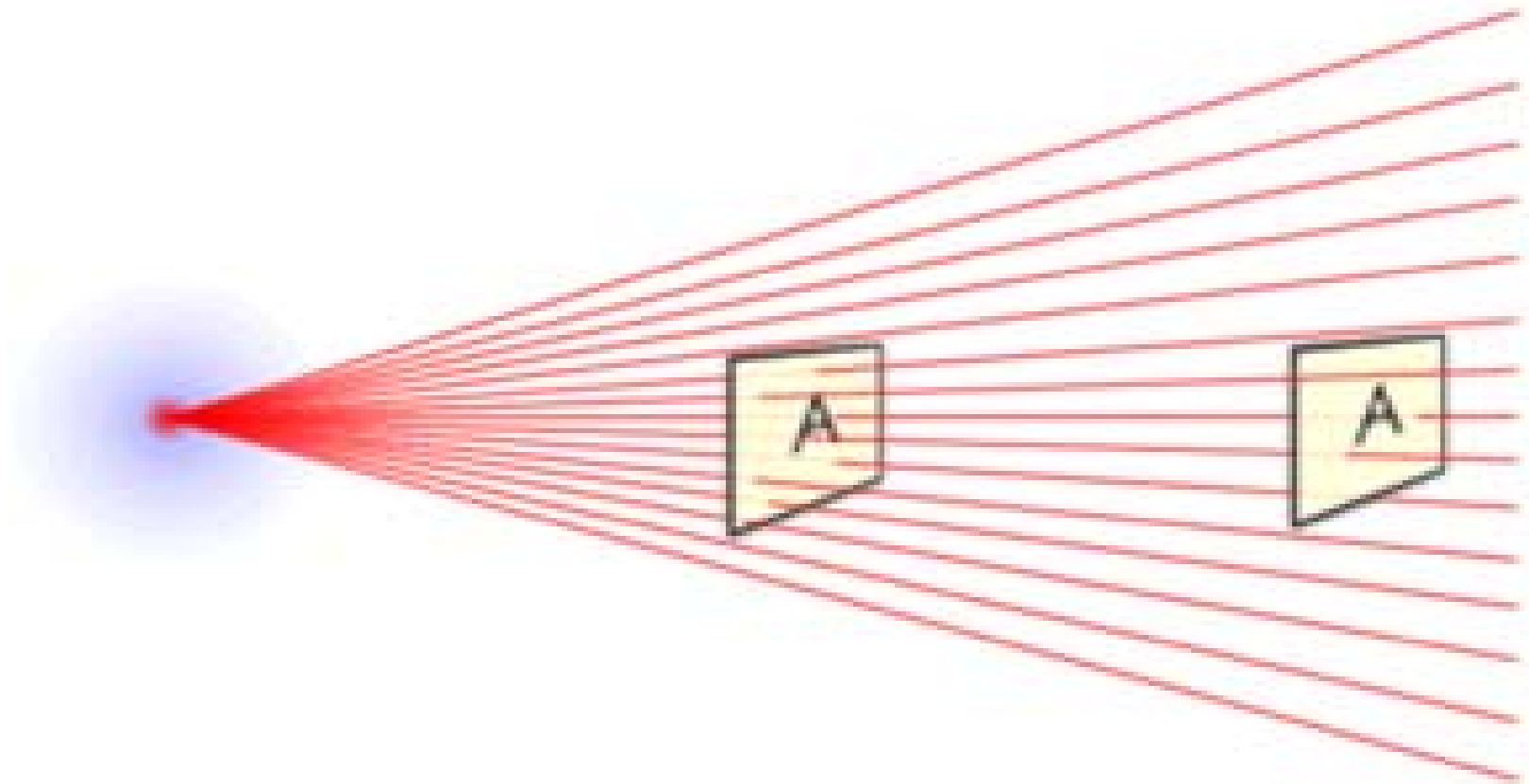
# Radio Wave Propagation

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- Term used to explain how radio waves behave when they are transmitted.
- Mechanism are diverse, but characterized by reflection, diffraction and scattering.
- In free space all electromagnetic waves obey inverse-square law.
- Which states electromagnetic wave's strength in proportional to  $1/(x)^2$ .



# Inverse Square Law





# Path Loss

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- Path loss is the phenomenon which occurs when the received signal becomes weaker and weaker due to increasing distance between mobile and base station. Path loss is also influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height and location of antennas.



# Path Loss

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

# Path Loss (Free-space)

- Definition of path loss  $L_p$ :

$$L_p = \frac{P_t}{P_r},$$

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.

- The higher the frequency, the higher the attenuation. It should be noted that this simple formula is valid only for land mobile radio systems close to the base station.



# Free Space Propagation Model

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- Predict received signal strength.
- Transmitter and receiver are in line-of-sight.
- Satellite communication and Microwave radio links undergo free space propagation.
- Large-Scale radio wave propagation models predicts the received power decays as a function of T-R distance.



# Friis Free Space Equation

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

- $P_t$  is the transmitted power.
- $P_r(d)$  is the received power.
- $G_t$  is the transmitter antenna gain.
- $G_r$  is the receiver antenna gain.
- $d$  is the T-R separation distance in meters.
- $L$  is the system loss factor.
- $\lambda$  is the wavelength in meters.



# Numerical

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- If a transmitter produces 50W of power, express the transmitter power in units of (a) dBm (b) dBW. If 50W is applied to unity gain antenna with a 900 MHz carrier frequency, find the received power in dBm at a free space distance of 100m from the antenna. What is  $P_r(10 \text{ Km})$ ? Assume unity gain for the receiver antenna.



# Radio Propagation Models

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- Also known as Radio Wave or Radio Frequency Propagation Model.
- Empirical mathematical formulation which includes:
  - Characterization of radio wave propagation
  - Function of frequency
  - Distance
  - Other condition
- Single model developed to:
  - Predict behavior of propagation
  - Formalizing the way radio waves are propagated
  - Predict path loss in the coverage area





# Characteristics

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- Path loss is dominant factor.
- Models typically focus on path loss realization.
- Predicting:
  - Transmitter coverage area.
  - Signal distribution representation.
- Telecommunication link encounter these conditions.
  - Terrain
  - Path
  - Obstructions
  - Atmospheric conditions
- Different model exist for different types of radio links.
- Model rely on median path loss.



# Development Methodology

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- Radio propagation model practical in nature.
- Means developed based on large collection of data.
- In any model the collection of data has to be sufficient large to provide enough likeness.
- Radio propagation models do not point out the exact behavior of a link.
- They predict most likely behavior.



# Variations

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- Different models needs of realizing the propagation behavior in different condition.
- Types of Models for radio propagation:
  - Models for outdoor attenuations.
  - Models for indoor attenuations.
  - Models for environmental attenuations.



# Models For Outdoor Attenuations

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- Near Earth Propagation Models
  - Foliage Model
    - Weissberger's MED Model
    - Early ITU Model
    - Updated ITU Model
      - One Woodland Terminal Model
      - Single Vegetative Obstruction Model



# Contd.

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- Terrain Model
  - Egli Model
  - ITU Terrain Model
- City Model
  - Young Model
  - Okumura Model
  - Hata Model For Urban Areas
  - Hata Model For Suburban Areas
  - Hata Model For Open Areas
  - Cost 231 Model
  - Area to Area Lee Model
  - Point to Point Lee Model



# Models For Indoor Attenuations

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- ITU Model For Indoor Attenuations
- Log Distance Path loss Model



# Models For Environmental Attenuations

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- Rain Attenuation Model
  - ITU Rain Attenuation Model
  - ITU Rain Attenuation Model For Satellites
  - Crane Global Model
  - Crane Two Component Model
  - Crane Model For Satellite Paths
  - DAH Model



# Okumura Model

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- Used for signal prediction in Urban areas.
- Frequency range 150 MHz to 1920 MHz and extrapolated up to 3000 MHz.
- Distances from 1 Km to 100 Km and base station height from 30 m to 1000 m.
- Firstly determined free space path of loss of link.
- Model based on measured data and does not provide analytical explanation.
- Accuracy path loss prediction for mature cellular and land mobile radio systems in cluttered environment.





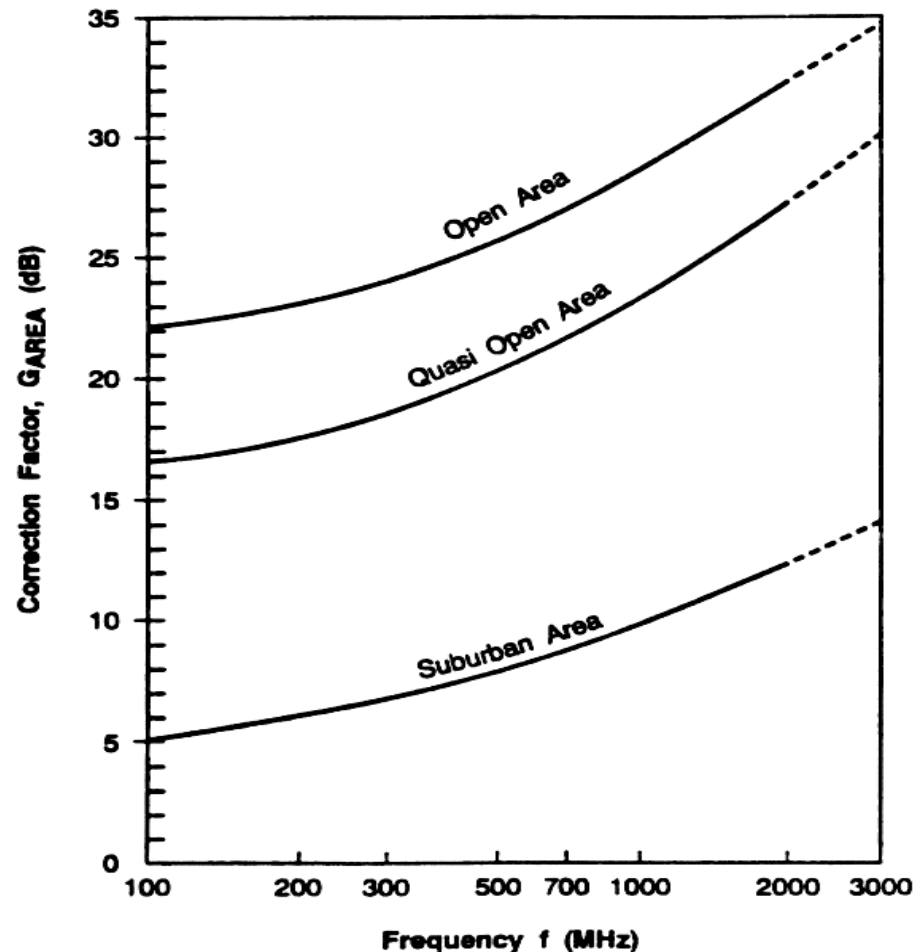
# Formulae

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$$L_{50}(\text{dB}) = L_F + A_{mu}(f, d) - G(h_{te}) - G(h_{re}) - G_{AREA}$$

- $L_{50}$  = Percentile value or median value.
- $L_F$  = Free space propagation loss.
- $A_{mu}$  = Median attenuation relative to free space.
- $G(h_{te})$  = Base station antenna height gain factor.
- $G(h_{re})$  = Mobile antenna height gain factor.
- $G_{AREA}$  = Gain due to the type of environment.

# Correction Factor $G_{AREA}$



**Figure 4.24** Correction factor,  $G_{AREA}$ , for different types of terrain [from [Oku68] © IEEE].



# Numerical

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- Find the median path loss using Okumura's model for  $d = 50$  Km,  $h_{te} = 100$  m,  $h_{re} = 10$  m in a suburban environment. If the base station transmitter radiates an EIRP of 1 kW at a carrier frequency of 1900 MHz, find the power at the receiver (assume a unity gain receiving system). P-152



# Hata Model Urban Areas

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- Most widely used model in Radio frequency.
- Predicting the behavior of cellular communication in built up areas.
- Applicable to the transmission inside cities.
- Suited for point to point and broadcast transmission.
- 150 MHz to 1.5 GHz, Transmission height up to 200m and link distance less than 20 Km.



# Formulae

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$$L_U = 69.55 + 26.16 \log f - 13.82 \log h_B - C_H + [44.9 - 6.55 \log h_B] \log d$$

- For small or medium sized city

$$C_H = 0.8 + (1.1 \log f - 0.7) h_M - 1.56 \log f$$

- For large cities

$$C_H = \begin{cases} 8.29 (\log(1.54h_M))^2 - 1.1, & \text{if } 150 \leq f \leq 200 \\ 3.2 (\log(11.75h_M))^2 - 4.97, & \text{if } 200 < f \leq 1500 \end{cases}$$



# Hata Model

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- $f_c$  (Frequency in Mhz) 150 to 1500 MHz
- $h_{te}$  (Height of Transmitter Antenna) 30 to 200m
- $h_{re}$  (Height of Receiving Antenna) 1 to 10 m
- $d$  (separation in T-R Km)
- $C_H$  correction factor for effective antenna height



# Numerical

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- Find the median path loss using Hata model for  $d = 10$  Km,  $h_{te} = 50$  m,  $h_{re} = 5$  m in a urban environment. If the base station transmitter at a carrier frequency of 900 MHz.



# Hata Model For Suburban Areas

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- Behavior of cellular transmission in city outskirts and other rural areas.
- Applicable to the transmission just out of cities and rural areas.
- Where man made structure are there but not high.
- 150 MHz to 1.5 GHz.





# Formulae

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$$L_{SU} = L_U - 2\left(\log \frac{f}{28}\right)^2 - 5.4$$

- $L_{SU}$  = Path loss in suburban areas.  
Decibel
- $L_U$  = Average path loss in urban areas.  
Decibel
- $f$  = Transmission frequency. MHz



# Hata Model For Open Areas

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- Predicting the behavior of cellular transmission in open areas.
- Applicable to the transmissions in open areas where no obstructions block the transmission link.
- Suited for point-to-point and broadcast links.
- 150 MHz to 1.5 GHz.



# Formulae

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$$L_o = L_u - 4.78 (\log f)^2 + 18.33 \log f - 40.97$$

- $L_o$  = Path loss in open areas. Decibel
- $L_u$  = Path loss in urban areas. Decibel
- $f$  = Transmission frequency. MHz