WHAT TO LEARN

- The Wireless Channel (Lectures 5 and 6)
- Transmission Fundamentals (CTFT, DTFT,DFT/FFT) (Lecture 7)
- Orthogonal Frequency Division Multiplexing- OFDM (Lecture 8)
- Spread Spectrum (Lecture 10)
- Coding and Error Control (Lecture 11)
- Cellular Wireless Networks (Lecture 12)
- Short-Range Wireless Technologies & Applications of Wireless Technologies in IoT (Lecture 13)

MOBILE SYSTEM-HT25 LECTURE 5: THE WIRELESS CHANNEL-PART I

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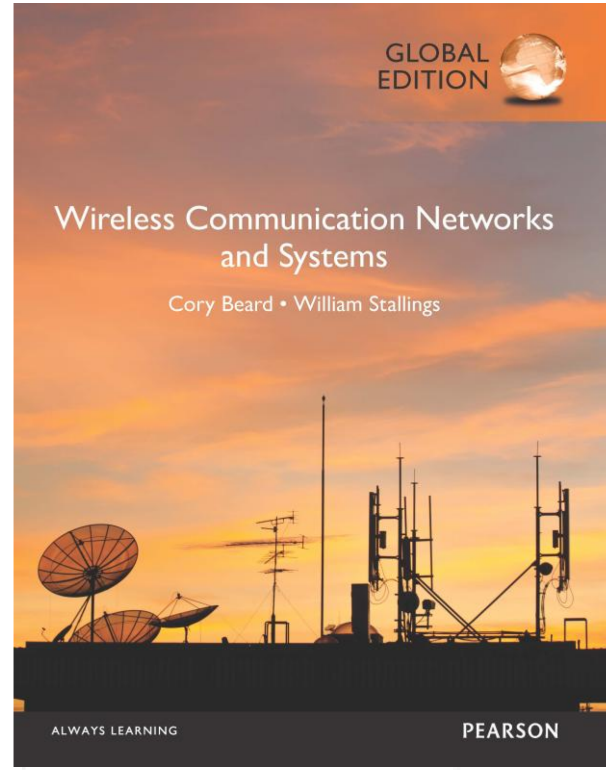
Faculty of Technology and Society Department of Computer Science and Media Technology Malmö University

Most slides are primarily adapted from Beard & Stallings (2016), Wireless Communication Networks and Systems (Chapter 6)

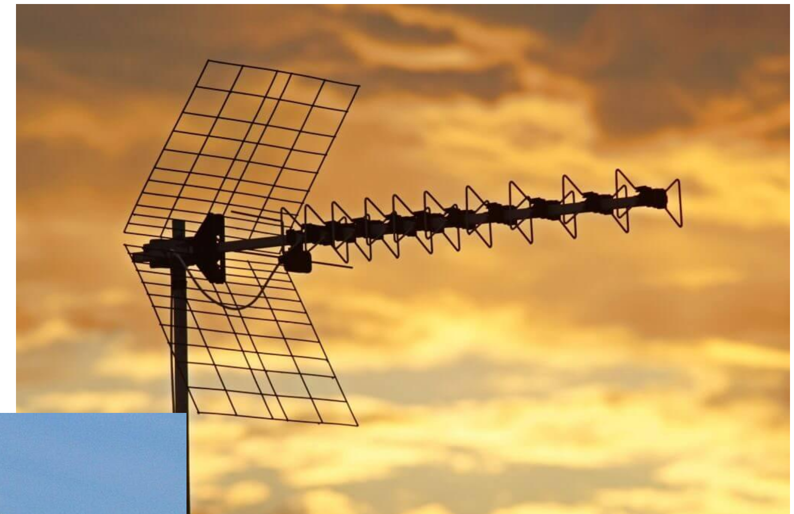


Wireless Communication Networks and Systems

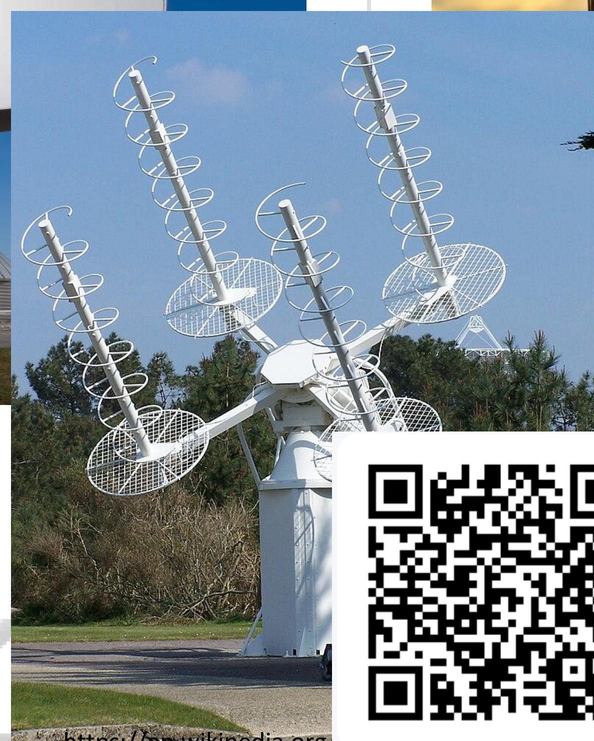
1st edition, Global edition

Cory Beard, William Stallings

ANTENNAS



https://www.rantecantennas.com/blog/slotted-array-antennas-your-guide-to-the-top-benefits/



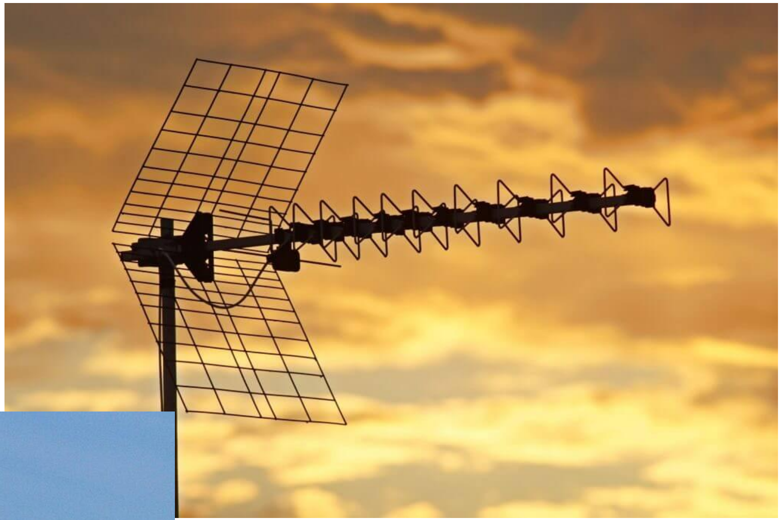
Can anyone give examples of antennas you see in daily life?

1 Go to wooclap.com

2 Enter the event code in the top banner

Event code
HMTZEN

ANTENNAS



https://www.rantecantennas.com/blog/slotted-array-antennas-your-guide-to-the-top-benefits/

https://en.wikipedia.org/wiki/

Can anyone give examples of antennas you see in daily life?

Wi-Fi router, smartphone, car radio antenna, …

ANTENNAS

- An antenna is an electrical conductor or system of conductors
  - Transmission - radiates electromagnetic energy into space
  - Reception - collects electromagnetic energy from space
- In two-way communication, the same antenna can be used for transmission and reception.

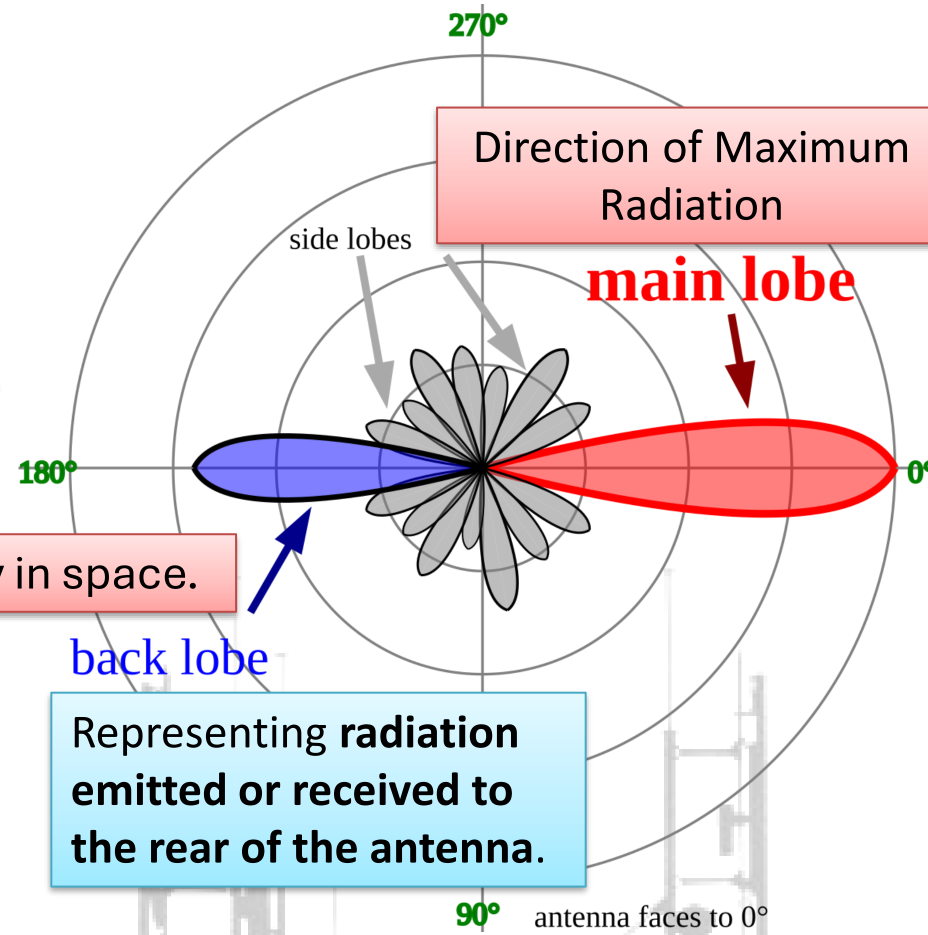
A translator between electrical signals and electromagnetic waves.

RADIATION PATTERNS

- **Radiation Pattern**
  - Graphical representation of radiation properties of an antenna
  - Depicted as two-dimensional cross section

Shows how an antenna distributes energy in space.

- **Reception Pattern**
  - Receiving antenna's equivalent to radiation pattern



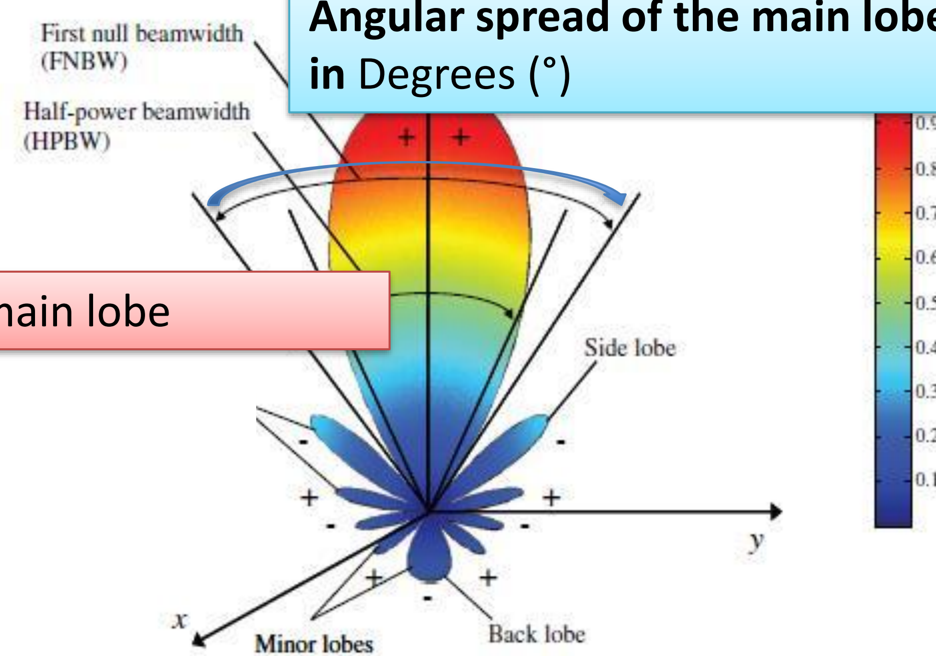
RADIATION PATTERNS

- **Side Lobes**
  - Extra energy in directions outside the main lobe

Side lobes are *all* the lobes except the main lobe

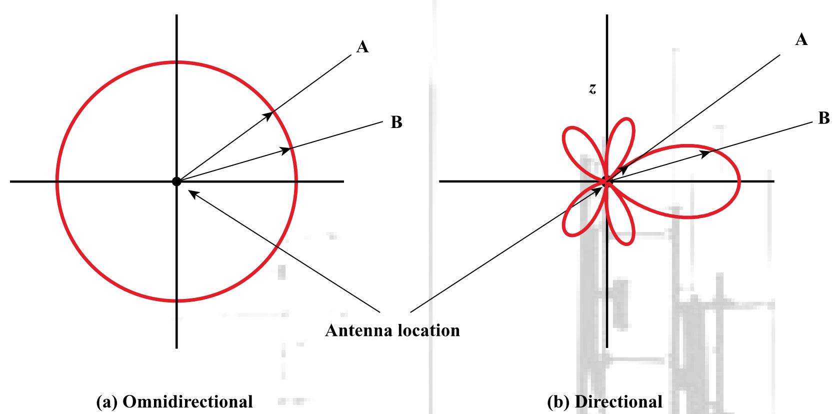
- **Beamwidth**
  - Measure of directivity of antenna

Angular spread of the main lobe in Degrees (°)



TYPES OF ANTENNAS

- Isotropic Antenna
- Omnidirectional Antennas
- Directional Antennas

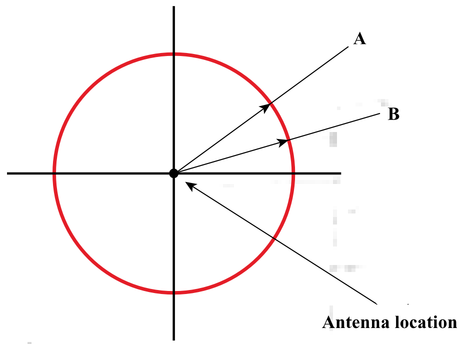


6.1 ANTENNA RADIATION PATTERNS

TYPES OF ANTENNAS

- Isotropic Antenna
  - Radiates power equally in all directions (3D)
- Omnidirectional Antennas
  - Radiate power equally in one plane (usually the horizontal plane) but not in all 3D directions.

Dipole Antennas

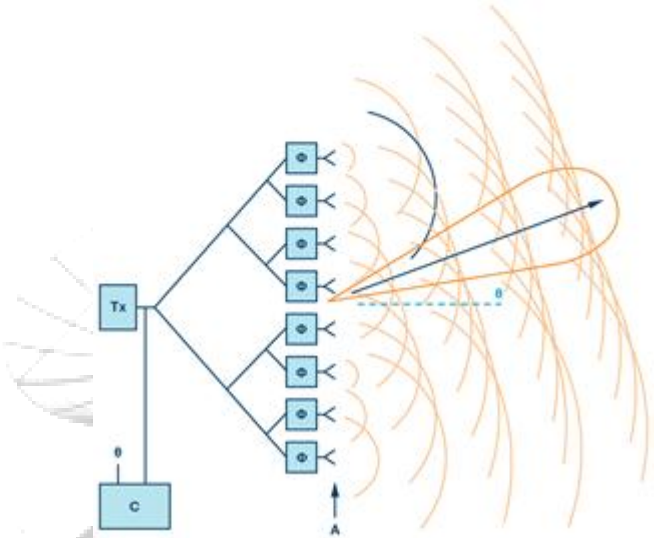


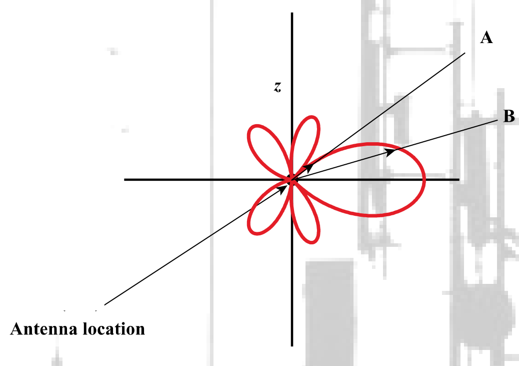
(a) Omnidirectional

TYPES OF ANTENNAS

Parabolic Reflective Antenna

- Directional Antennas
  - Often made up of **arrays of antenna elements**
    - In a linear array or other configuration
    - Signal amplitudes and phases to each antenna are adjusted to create a directional pattern
    - Very useful in modern systems





(b) Directional

DISCUSSION TIME I

Imagine a perfect antenna that radiates equally in all directions — an isotropic antenna. It seems ideal, but would it really be practical?

Work in small groups to discuss what would happen to signal strength if energy spreads everywhere instead of being directed. Compare this to how light behaves — a glowing bulb versus a flashlight.

Think about Wi-Fi routers, satellite dishes, and car antennas: Would you prefer a wide beam that covers a broad area or a narrow beam that concentrates energy in one direction? Discuss what types of antennas are appropriate for each.

CLASS DISCUSSION

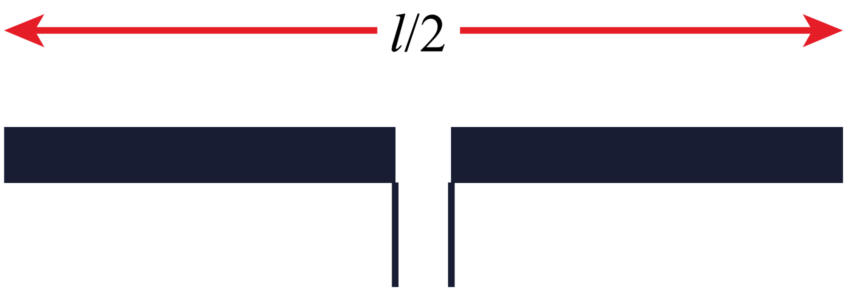
- A truly isotropic antenna would waste most of its energy because it spreads power equally in every direction, leaving very little signal strength for any one receiver.
- A truly isotropic antenna cannot exist in practice (**Isotropic antenna is theoretical**, not just inefficient) .
  - Satellite dishes use highly **directional antennas** to focus energy toward a specific point in space, giving maximum range and signal strength.
  - Wi-Fi routers typically use **omnidirectional** (horizontal) antennas to cover nearby devices in all directions, trading range for broad **coverage**.
  - Car antennas are also **omnidirectional**, since the vehicle moves and needs to receive signals from any direction.
- Engineers choose shapes and beam widths to balance **coverage, efficiency, and interference control (Limiting signals from unwanted directions; Preventing overlap with other nearby antennas or networks; …).**

TYPES OF ANTENNAS

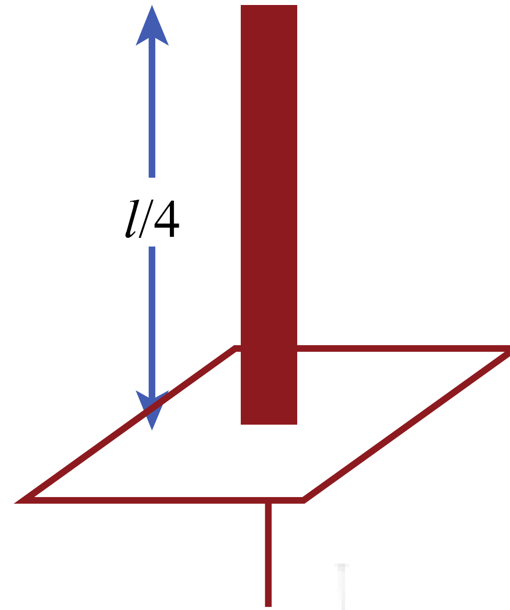
- Dipole Antennas
  - The most **fundamental practical antenna** type.
  - Made of **one/two conductors** (wires or rods).
  - Radiation pattern: **omnidirectional** in the horizontal plane,

Types:

- **Half-wave dipole (Hertz antenna):**
  - Total length ≈ $\lambda/2$ (each arm $\lambda/4$).
- **Quarter-wave vertical dipole (Marconi antenna):**
  - Mounted vertically over a conducting surface (ground plane).
  - Used for broadcasting and mobile communications.

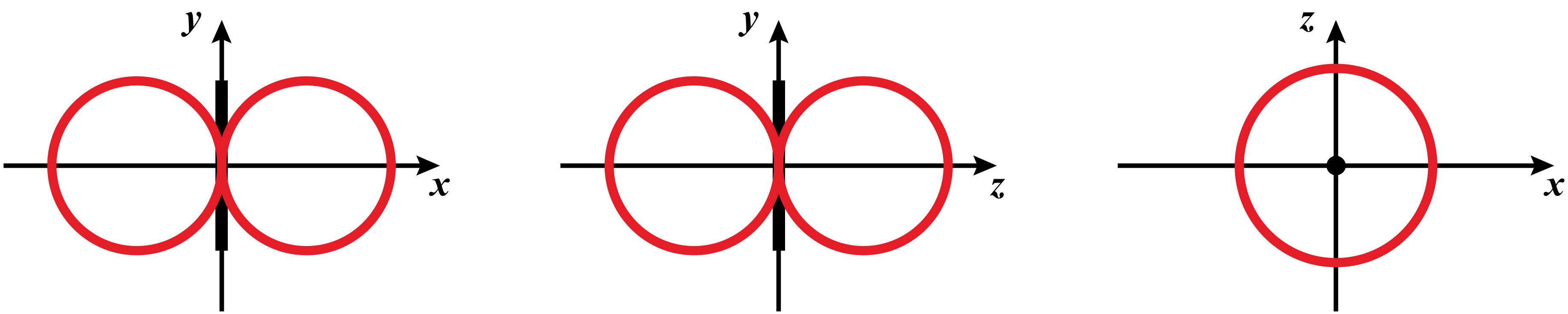


(a) Half-wave dipole



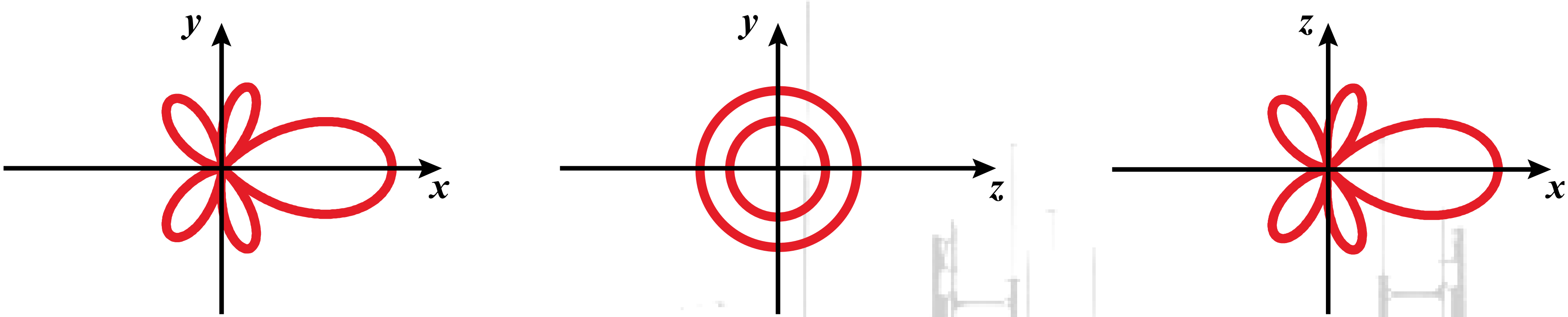
(b) Quarter-wave antenna

6.2 SIMPLE ANTENNAS



Side view (*xy*-plane) Side view (*zy*-plane) Top view (*xz*-plane)

(a) Simple dipole



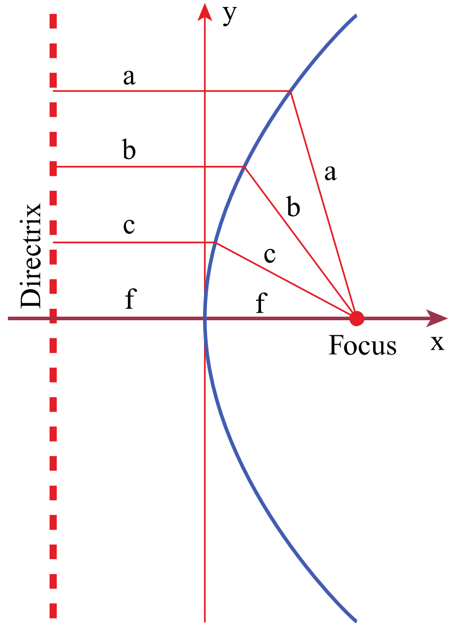
Side view (*xy*-plane) Side view (*zy*-plane) Top view (*xz*-plane)

(b) Directed antenna

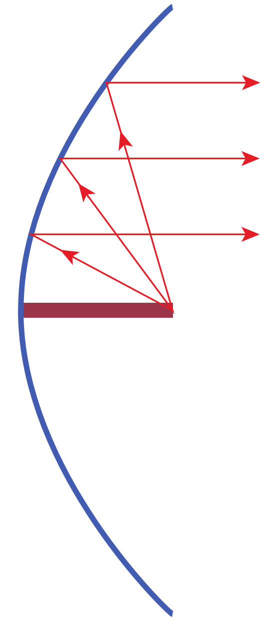
6.3 RADIATION PATTERN IN THREE DIMENSIONS

TYPES OF ANTENNAS

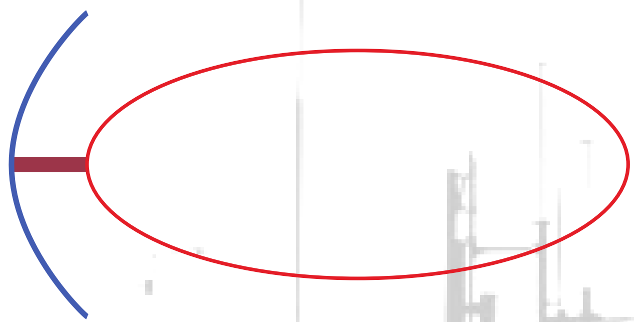
- **Parabolic Reflective Antenna**
  - Uses a **parabolic-shaped reflector** to **focus radio waves** into a narrow beam.
  - Produces **high gain** and **narrow beamwidth** (very directional).
  - Common in **satellite dishes**, **radar systems**, **microwave links**.



(a) Parabola



(b) Cross section of parabolic antenna showing reflective property



(c) Cross section of parabolic antenna showing radiation pattern

6.4 PARABOLIC REFLECTIVE ANTENNAS

ANTENNA GAIN

- Antenna gain: Shows how much stronger the antenna makes the signal in a given direction compared to an isotropic antenna (one that radiates equally in all directions).
- Effective area
  - represents the **maximum power** an antenna can receive **from a plane electromagnetic wave** arriving from the direction in which the antenna has its **maximum gain**.

ANTENNA GAIN

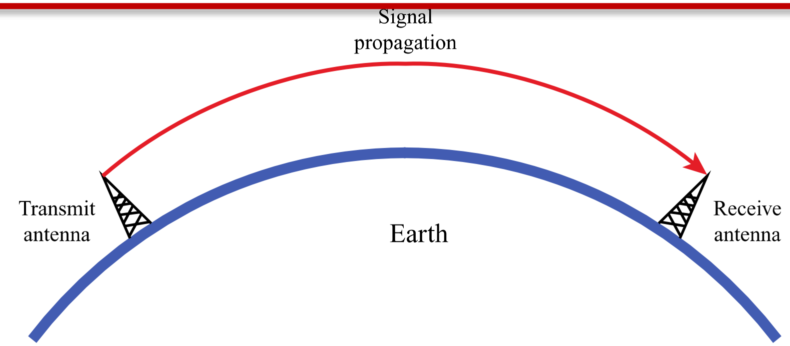
- Relationship between antenna gain and effective area

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f^2 A_e}{c^2}$$

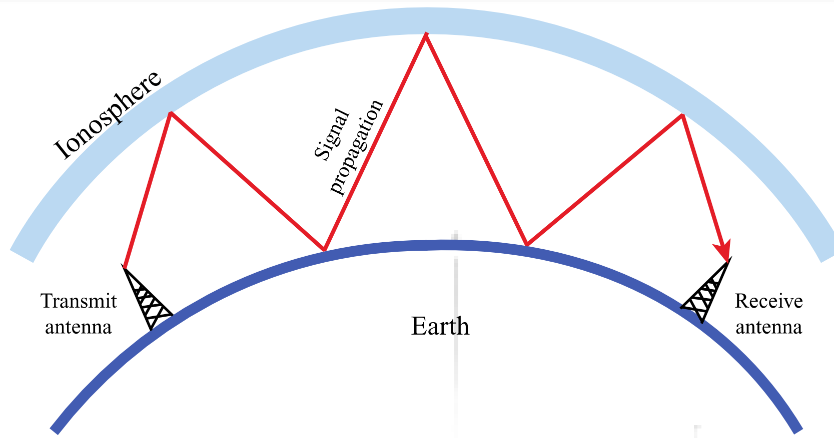
- G = antenna gain
- A_e = effective area
- f = carrier frequency
- c = speed of light ($\approx 3 \times 10^8$ m/s)
- λ = carrier wavelength

PROPAGATION MODES

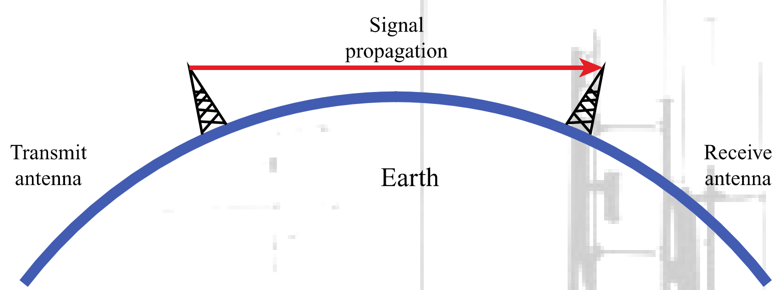
- Ground-wave propagation
- Sky-wave propagation
- Line-of-sight propagation



(a) Ground wave propagation (below 2 MHz)



(b) Sky wave propagation (2 to 30 MHz)



(c) Line-of-sight (LOS) propagation (above 30 MHz)

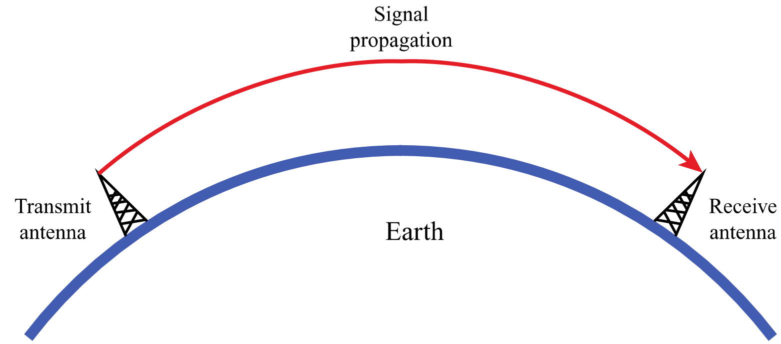
6.5 WIRELESS PROPAGATION MODES

GROUND WAVE PROPAGATION

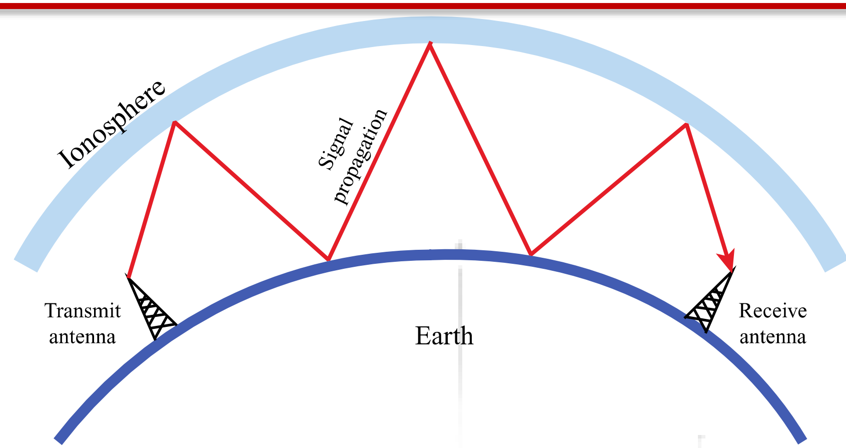
- Follows contour of the earth
- Can propagate considerable distances (up to a few 100 km)
- Frequencies up to 2 MHz

$$\lambda = \frac{v}{f}$$

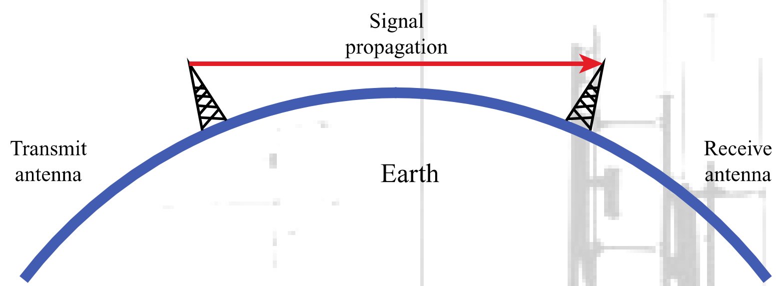
v = Speed of the wave



(a) Ground wave propagation (below 2 MHz)



(b) Sky wave propagation (2 to 30 MHz)

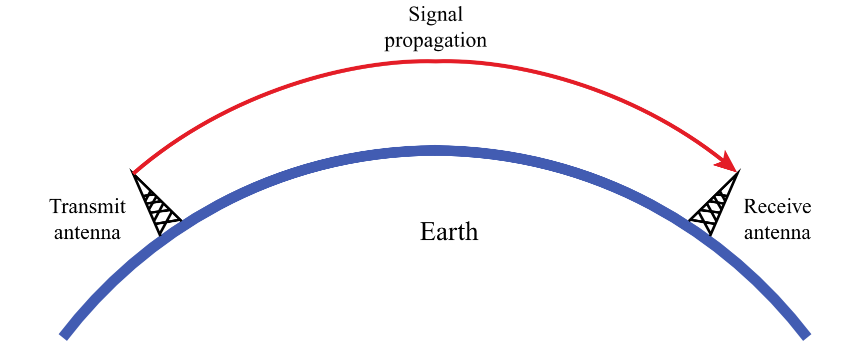


(c) Line-of-sight (LOS) propagation (above 30 MHz)

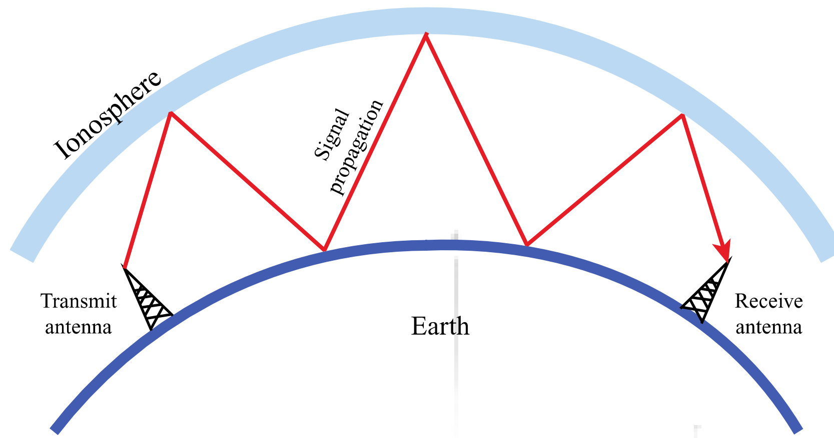
6.5 WIRELESS PROPAGATION MODES

SKY WAVE PROPAGATION

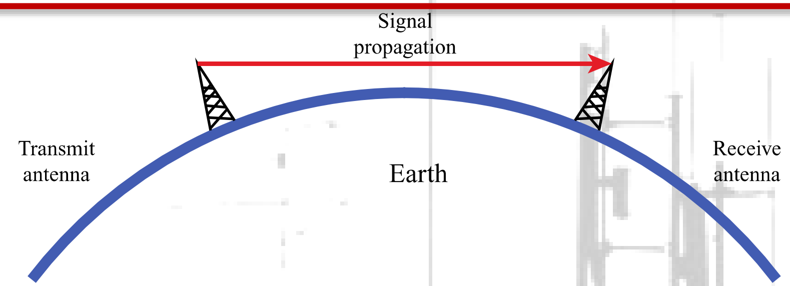
- Signal reflected from ionized layer of atmosphere back down to earth
- Signal can travel a number of hops, back and forth between ionosphere and earth's surface
- At medium frequencies (2–30 MHz).
- Long distances (1000s km)



(a) Ground wave propagation (below 2 MHz)



(b) Sky wave propagation (2 to 30 MHz)



(c) Line-of-sight (LOS) propagation (above 30 MHz)

6.5 WIRELESS PROPAGATION MODES

LINE-OF-SIGHT PROPAGATION

Transmitting and receiving antennas must be within line of sight

When It Happens:

- **Satellite communication:**
  Signals above **30 MHz** go straight through the ionosphere, so they need a clear line of sight.
- **Ground communication:**
  Antennas must be within an **effective line of sight**.
  - Allow **high data rates, small antennas, reliable local coverage,**

DISCUSSION TIME II

Not all radio signals travel the same way. Some hug the Earth's surface, some bounce off the upper atmosphere, and others need a clear line of sight. In your groups, try to connect each of the following technologies — **AM radio, ham (amateur) radio, TV broadcasting, Wi-Fi, and satellite communication** — to the three main propagation modes: **Ground-wave, Sky-wave, and Line-of-Sight.**

Here are a few hints to guide your reasoning:

- **AM radio** is Local to regional.
- **Ham or amateur radio** is Regional to worldwide.
- **Broadcast (TV or FM)** work at **very high frequencies.**

CLASS DISCUSSION

- **Ground-wave propagation:** Follows the Earth's surface at low frequencies (below 2 MHz). Used by **AM radio** and **maritime communication** because it can reach receivers beyond the horizon.
- **Sky-wave propagation:** Bounces off the ionosphere at medium frequencies (2–30 MHz). Used by **ham radio, CB radio, …** for long-distance global links.
- **Line-of-Sight propagation:** Travels straight and is easily blocked by terrain or buildings. Used by **TV broadcasting**, **microwave links**, **Wi-Fi**, and **satellite communication** for high-frequency, high-bandwidth systems.

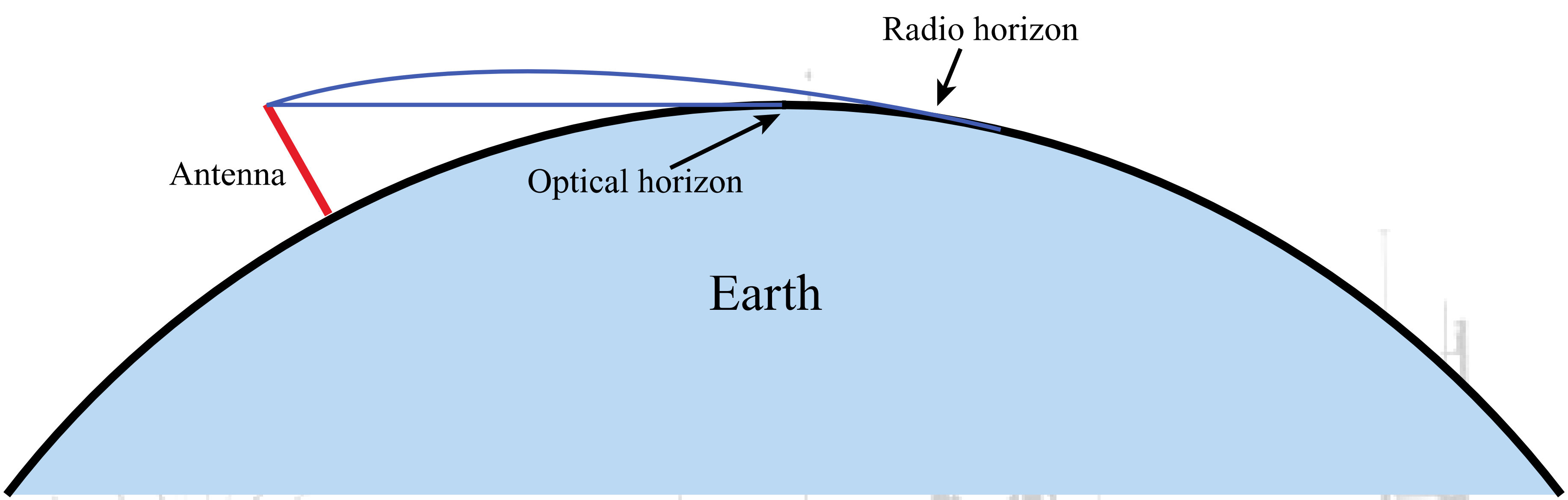
Each propagation mode is chosen based on **frequency range, desired distance, and environmental conditions** — that's why no single method fits all wireless systems.

Refraction (Bending of Waves)

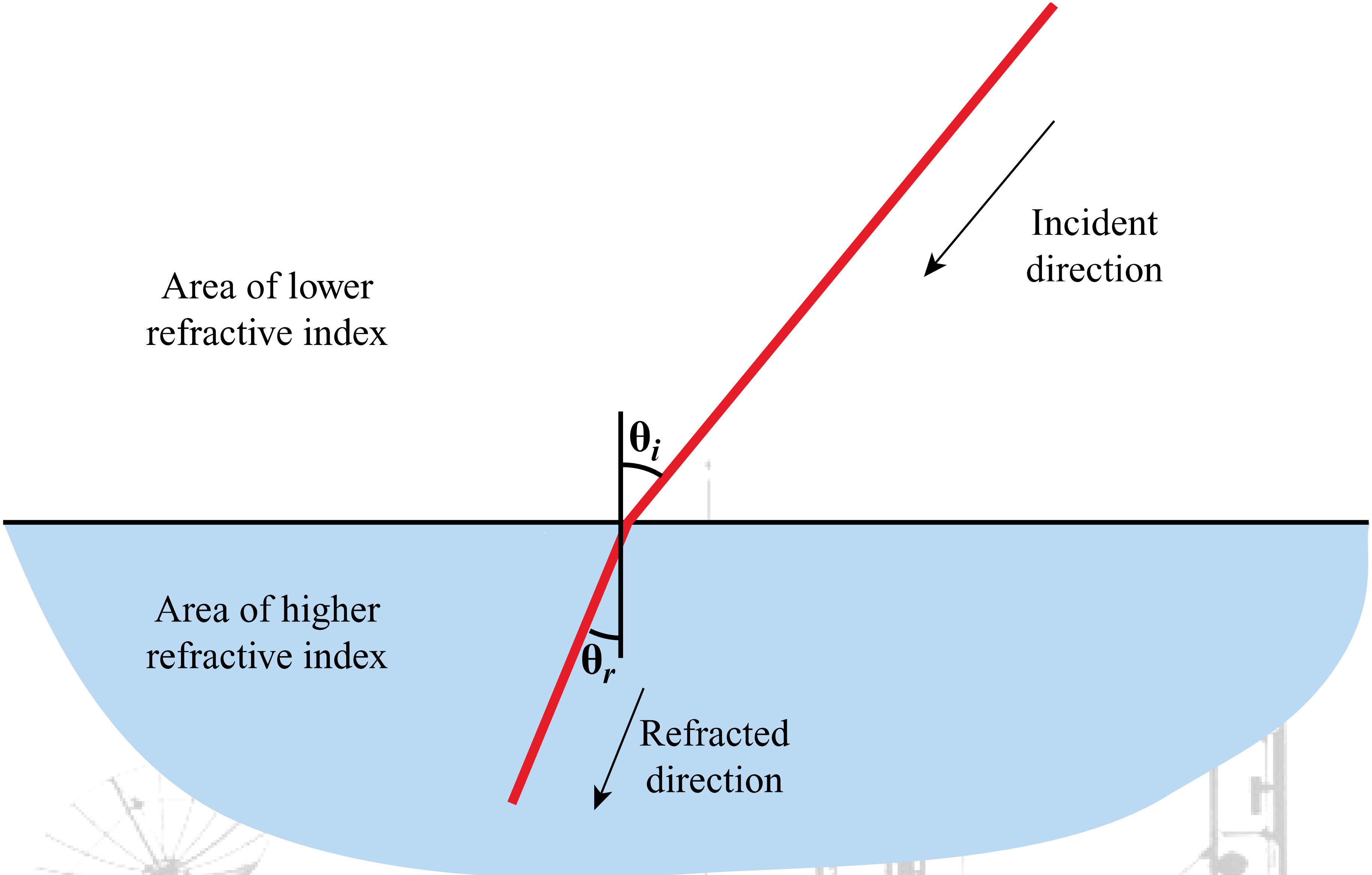
The **atmosphere bends** radio waves slightly because air density changes with height.

The **wave speed changes**, causing the wave to **curve** instead of travel straight.

This lets signals reach **a little farther** than the visible horizon.



6.7 OPTICAL AND RADIO HORIZONS



6.6 REFRACTION OF AN ELECTROMAGNETIC WAVE

LINE-OF-SIGHT EQUATIONS

- Optical line of sight

$$d = 3.57\sqrt{h}$$

- Effective, or radio, line of sight

$$d = 3.57\sqrt{\mathrm{K}h}$$

how far a radio signal can travel based on **antenna height**

  - d = distance between antenna and horizon (km)
  - h = antenna height (m)
  - K = adjustment factor to account for refraction, rule of thumb K = 4/3

LINE-OF-SIGHT EQUATIONS

- Maximum distance between two antennas for LOS propagation:

$$3.57\left(\sqrt{\mathrm{K}h_1} + \sqrt{\mathrm{K}h_2}\right)$$

  - h_1 = height of first antenna
  - h_2 = height of second antenna

DISCUSSION: WHY TALL TOWERS MATTER

- If you double the height of a tower, how much farther can you actually see? Does the range double, or does it increase more slowly?
- Why do we build very tall towers?
- What limits tower height?
- *Discuss when might engineers prefer many short towers instead of one huge tower?*

$$\boxed{d = 3.57\sqrt{\mathrm{K}h}}$$

DISCUSSION: WHY TALL TOWERS MATTER

•Doubling tower height does **not** double the range.
The line-of-sight distance increases with the **square root of the height**:
$d \propto \sqrt{h}$
→ Doubling height increases range by about $\sqrt{2} \approx$ **1.4**×, not 2×.

Why tall towers still help:

- Fewer obstacles → better line-of-sight
- Wider coverage area → fewer towers needed
- Reduced interference from ground reflections

Why not infinitely tall towers:

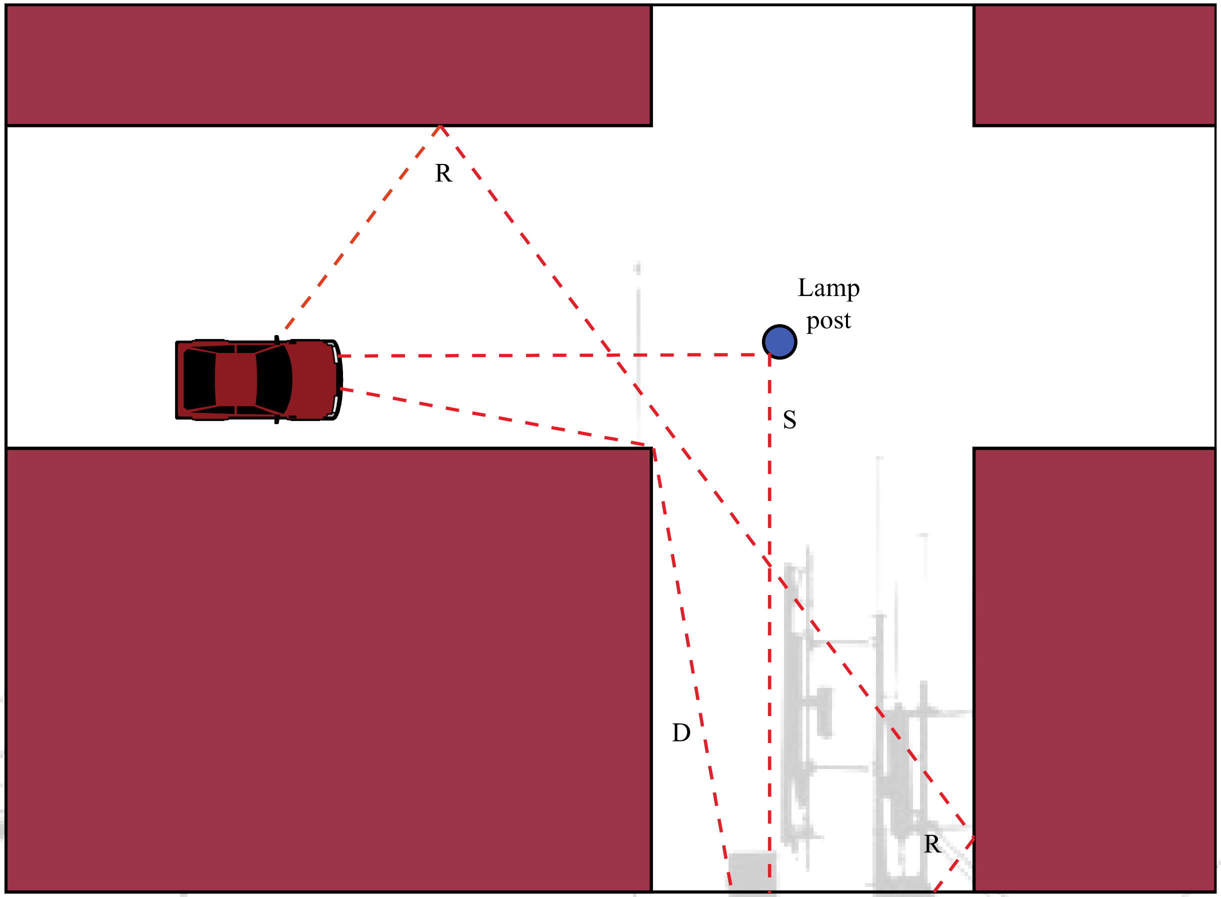
- High construction and maintenance cost
- Wind and structural limits
- Frequency reuse requires smaller coverage areas in modern cellular systems

Taller towers extend range but with **diminishing returns** — engineers must balance **height, cost, and cell density** for efficient network design

FIVE BASIC PROPAGATION MECHANISMS

1. Free-space propagation
2. Transmission
   - Through a medium
   - Refraction occurs at boundaries
3. Reflections
   - Waves impinge upon surfaces that are large compared to the signal wavelength
4. Diffraction
   - Secondary waves behind objects with sharp edges
5. Scattering
   - Interactions between small objects or rough surfaces

REFLECTION, DIFFRACTION, AND SCATTERING



LOS WIRELESS TRANSMISSION IMPAIRMENTS

- Attenuation and attenuation distortion
- Free space loss
- Noise
- Multipath
- Refraction
- Mobility

Next Lecture