MASINDE MULIRO UNIVERSITY OF SCIENCE & TECHNOLOGY

ECE 516E – ANTENNA & RADIOWAVE PROPAGATION

STUDY GUIDE: RADIO FREQUENCY COMMUNICATION & PROPAGATION MODES

1. OBJECTIVE

This guide covers the primary frequency bands used in radio communication (LF, MF, HF, VHF, UHF) and the three fundamental propagation modes (Ground, Sky, and Space Wave). Understanding the relationship between frequency and propagation is crucial for designing and troubleshooting any wireless system, from AM radio to satellite links.

2. RADIO FREQUENCY BANDS & CHARACTERISTICS

A common way to categorize radio waves is by frequency. Each band has unique propagation characteristics that make it suitable for specific radio wave applications.

Band Name	Frequency Range	Wavelength	Primary Propagation Mode(s)	Key Applications
LF (Low Frequency)	30 kHz - 300 kHz	10 km - 1 km	Ground Wave	Long-range navigation (LORAN-C), Time signals, Submarine comms
MF (Medium Frequency)	300 kHz - 3 MHz	1 km - 100 m	Ground Wave (day), Sky Wave (night)	AM radio broadcasting, Maritime comms, Avalanche beacons
HF (High Frequency)	3 MHz - 30 MHz	100 m - 10 m	Sky Wave	Shortwave broadcasting, Amateur radio, Aviation (over oceans), Military comms
VHF (Very High Frequency)	30 MHz - 300 MHz	10 m - 1 m	Space Wave (Line-of-Sight)	FM radio, TV broadcasts (VHF), Air traffic control, Marine VHF, Two-

				way land mobile radio
UHF (Ultra High Frequency)	300 MHz - 3 GHz	1 m - 10 cm	Space Wave (Line-of-Sight)	

2. RADIO WAVE PROPAGATION MODES

Radio Wave Propagation mode describes the path a radio wave takes between the transmitter and receiver.

2.1. Ground Wave Propagation

- **Mechanism:** Radio waves travel along the surface of the Earth, following its curvature. They are guided by the difference in conductivity between the air and the ground.

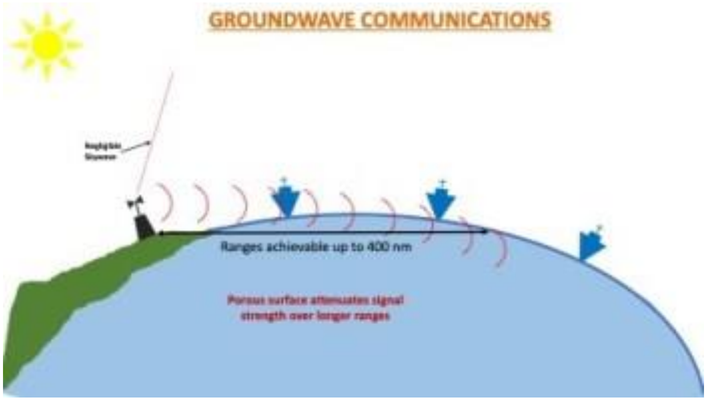

Figure 1. Ground Wave Propagation

- **Frequency Dependency: Dominates at LF and MF.** Efficiency decreases rapidly as frequency increases due to higher absorption losses in the ground. Practically unusable above ~3 MHz (start of HF).
- **Key Characteristics:**
  - **Stable and Reliable:** Not subject to the daily and seasonal variations that affect sky wave.
  - **Limited Range:** Range is a function of transmitted power and ground conductivity (better over seawater, worse over dry land). Typically a few hundred miles for MF.
- **Example:** An AM radio station can be received via ground wave during the day within its local coverage area.

2.2. Sky Wave Propagation (Ionospheric Propagation)

- **Mechanism:** Radio waves are **refracted** (bent) back to Earth by ionized layers in the upper atmosphere (the ionosphere). This allows for communication beyond the horizon, often over thousands of miles.

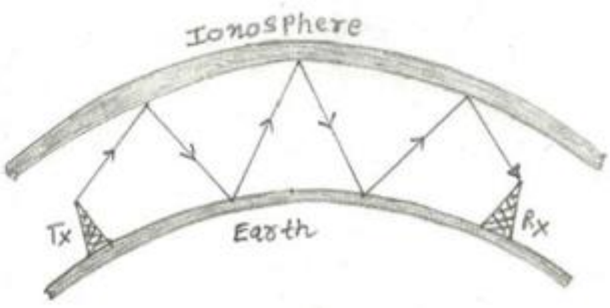

Figure 2. Sky Wave Propagation

- **Frequency Dependency:** ~~**Primary mode for HF**~~**.** The wave must be at a frequency that is high enough to penetrate the D and E layers but low enough to be refracted by the F layer. A critical frequency exists above which waves penetrate the ionosphere and escape into space.
- **Key Concepts:**
    - **Critical Frequency (fc):** The highest frequency that can be sent straight up and still be refracted back to Earth.
    - **Maximum Usable Frequency (MUF):** The highest frequency that can be used for sky wave communication between two specific points on Earth. MUF is always higher than *fc* for oblique paths.

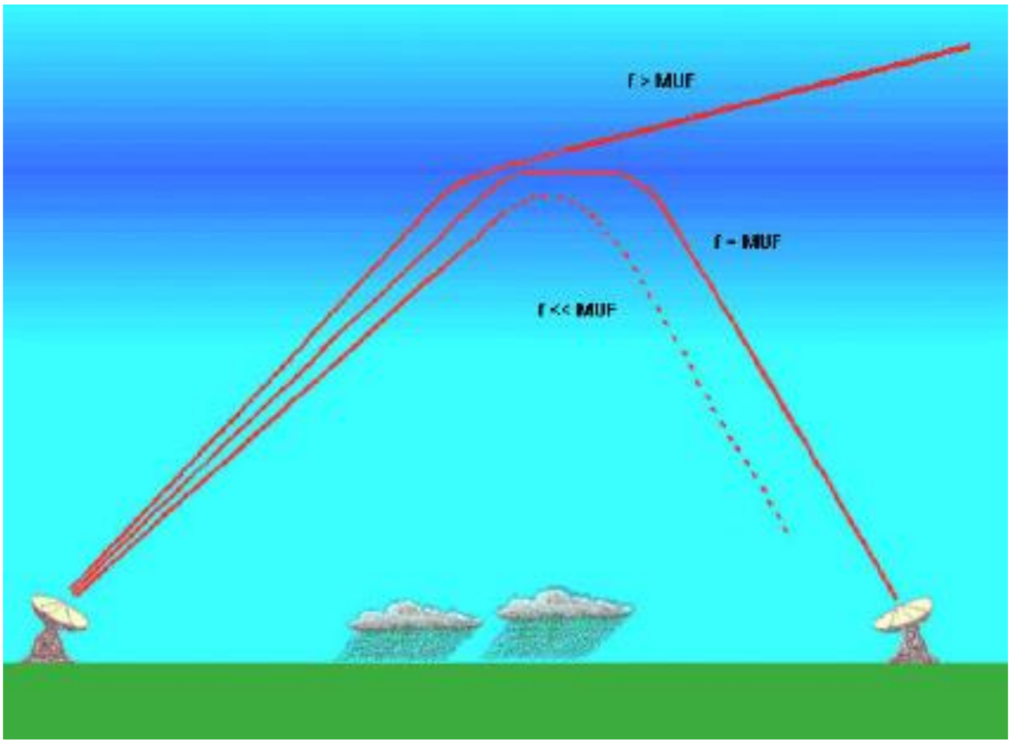

Figure 3. Maximum Usable Frequency

- **Skip Zone:** A region of poor reception between the farthest reach of the ground wave and the point where the sky wave first returns to Earth.

- **Key Characteristics:**
  - **Long Distance:** Enables intercontinental communication.
  - **Variable & Unpredictable:** Highly dependent on the sun (time of day, season, and the 11-year solar cycle). The ionosphere changes constantly, requiring dynamic frequency selection.
  - **Fading:** Common due to multiple layers and paths causing signal interference.
- **Example:** International shortwave radio broadcasts (e.g., BBC World Service).

2.3. Space Wave Propagation (Line-of-Sight)

- **Mechanism:** Encompasses waves that travel in a straight line from transmitter to receiver. This includes both the direct wave and the ground-reflected wave.

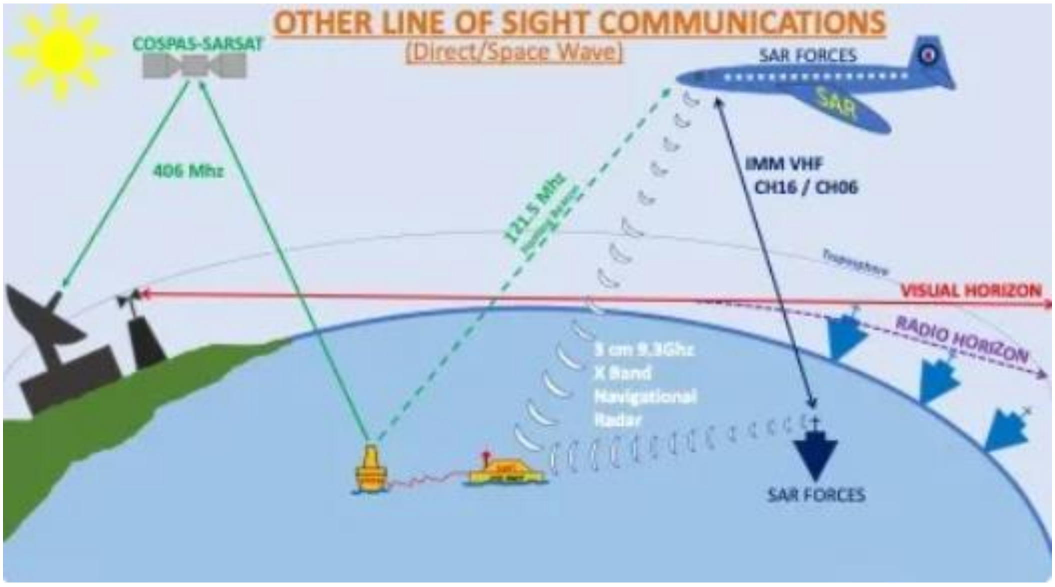

Figure 4. Space wave communication

- **Frequency Dependency: The only practical mode for VHF, UHF, and above.** These high frequencies penetrate the ionosphere and are not refracted back effectively. They are also absorbed quickly by the Earth, preventing ground wave propagation.
- **Key Concepts:**
  - **Line-of-Sight (LOS):** Requires a visual path between transmitter and receiver antennas. The radio horizon is approximately 4/3 times the geometric horizon due to atmospheric refraction.

- **Path Loss:** Follows the **Free Space Path Loss** formula: $L_p = (4\pi d / \lambda)^2$ (often expressed in dB). Loss increases with both distance and frequency.
- **Fresnel Zones:** Ellipsoidal areas around the direct LOS path that must be kept clear of obstructions to avoid diffraction loss. The **1st Fresnel zone** is most critical.
- **Multipath Fading:** The direct and ground-reflected waves can arrive out of phase, causing constructive or destructive interference.

- **Examples:** WiFi router to laptop, cell phone to tower, FM radio reception.

4. PRACTICE PROBLEMS & DISCUSSION QUESTIONS

1. Why can you hear a distant AM radio station (MF) clearly at night but only local stations during the day?

   Answer: During the day, the D layer of the ionosphere is strongly ionized and absorbs MF waves. At night, the D layer dissipates, allowing MF waves to propagate to the E and F layers and be refracted back to Earth via sky wave, greatly extending the station's range.

2. Calculate the free-space path loss for a 2.4 GHz WiFi signal over a distance of 50 meters.

   Answer: Using $L_p (dB) = 32.44 + 20\log_{10}(0.05) + 20\log_{10}(2400) \approx 32.44 + (-26.02) + 67.60 = 74.02$ dB.

3. A ship at sea needs to communicate with its home base 5000 km away. Which frequency band and propagation mode would be most appropriate? Why?

   Answer: HF band using sky wave propagation. Ground wave would not travel that far, and space wave (VHF/UHF) is impossible due to the Earth's curvature and the lack of a line-of-sight path. HF sky wave is specifically designed for such long-distance, over-the-horizon communication.

4. Why are cellular networks (UHF) built with many cell towers instead of a few very tall, high-power towers?

   Answer: UHF propagation is primarily line-of-sight (space wave). A single tower would have a limited coverage area due to the curvature of the Earth and obstacles. To provide coverage to a large number of users and reuse limited frequency spectrum efficiently, a cellular architecture with many low-power towers is used.

5. What is the primary reason GPS satellites use UHF frequencies (~1.5 GHz)?

   Answer: The UHF signal must penetrate the ionosphere with minimal refraction to reach Earth receivers accurately. Lower frequencies (HF) would be refracted by the ionosphere, introducing positioning errors. Higher frequencies (e.g., SHF) would suffer more from atmospheric absorption (rain fade).