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Antenna & Propagation

Basic Radio Wave Propagation

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Chapter Synopsis

In this course, the student will be exposed to the basic concept of radio wave propagation. Electromagnetic wave spectrum and frequency range. Furthermore, the fundamental equation for free space propagation. Lastly, the modes of propagation radio wave.

Teaching Outcome

At the end of this course student should be able to:

- Characterize the fundamentals of radio propagation and its modes.
- Understand the Electromagnetic wave spectrum and frequency range.
- Learn the fundamental equation for free space propagation.

Contents

Introduction

- When the antenna radiates a signal, it spreads in all over directions.
- Hence when the signal propagates through the space, the amplitude of signal decreases as the distance increases.
- The signal can travels several different paths from transmitter to receiver.
- The paths are depending: the frequency, atmospheric condition and also time of the day.

Concept of Radio Wave

- Whenever a high frequency current flows through conductor, its generate power and the power that spread through the space is called radiation.
- In free space electromagnetic waves travel at the speed of light, $c = 3 \times 10^8$m/s.
- As the wave travels through the free space, the strength of the signal reduces.

Properties of Electromagnetic (EM) Waves

- Speed of propagation
- Polarization of EM waves
- Rays and Wavefront
- Field Intensity and Power Density
- Attenuation and Absorption

Properties of Radio Waves

- Reflection
- Refraction
- Diffraction and Scattering
- Interference

Properties of Radio Waves

Reflection

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

Refraction

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

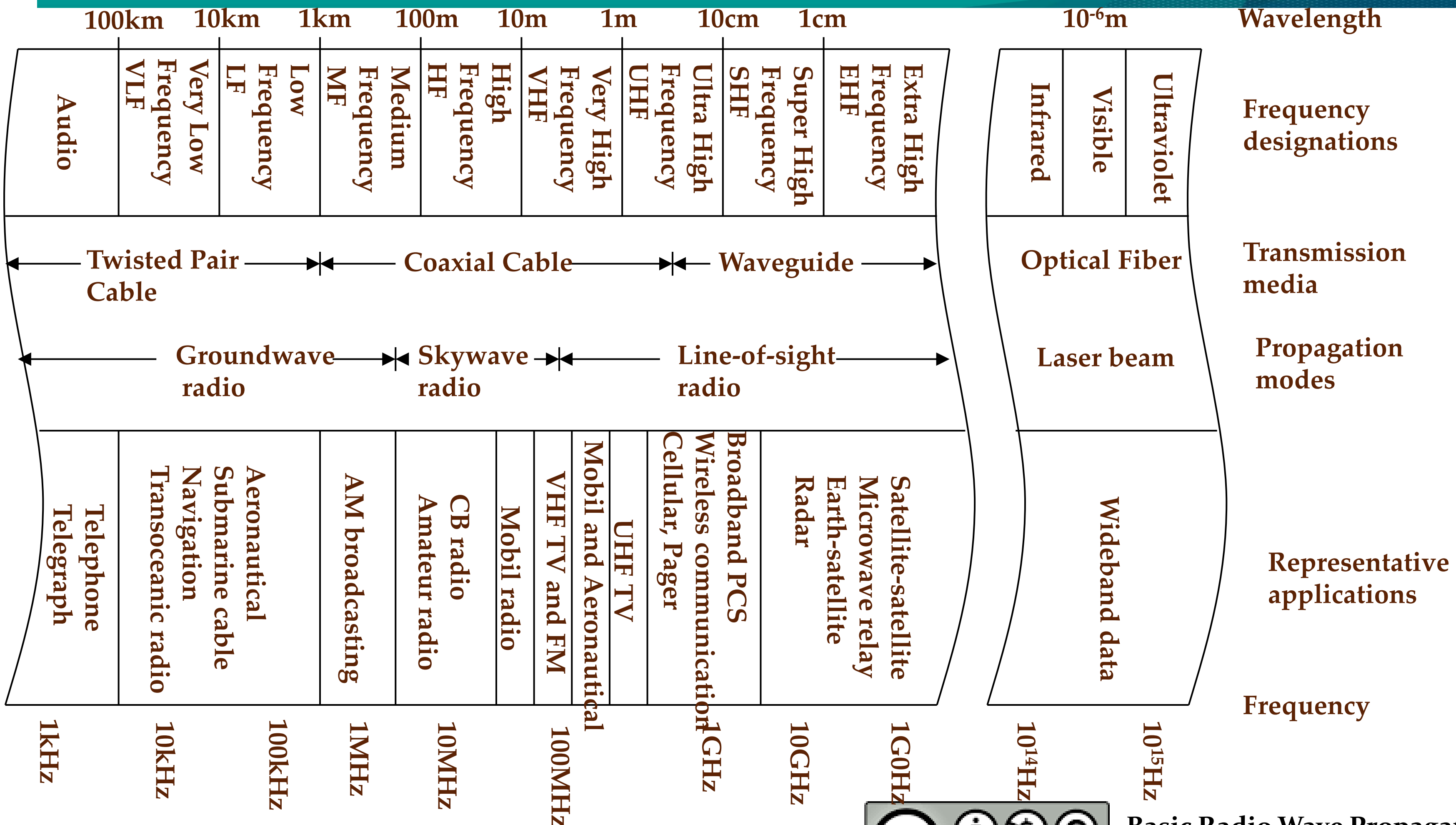
- Objects smaller than the wavelength of the propagation wave. E.g. foliage, street signs, lamp posts

Interference

Three Scale of Multiplicative Noise

- Path Loss
- Shadowing
- Fast Fading

Frequency Spectrum



Radio Frequencies Band Names

Band Name	Abbr.	Frequency	Wavelength	Examples of Usage
Extremely Low Frequency	ELF	3-30 Hz	10-100 Mm	Military application
Super Low Frequency	SLF	30-300 Hz	1-10 Mm	Power lines
Ultra Low Frequency	ULF	0.3-3 kHz	0.1-1 Mm	Monitoring earthquake
Very Low Frequency	VLF	3-30 kHz	10-100 km	Submarines
Low Frequency	LF	30-300 kHz	1-10 km	Beacons
Medium Frequency	MF	0.3-3 MHz	0.1-1 km	AM broadcast
High Frequency	HF	3-30 MHz	10-100 m	Short-wave radio
Very High Frequency	VHF	30-300 MHz	1-10 m	FM and TV broadcast
Ultra High Frequency	UHF	0.3-3 GHz	0.1-1 m	TV, WiFi, mobile phones, GPS
Super High Frequency	SHF	3-30 GHz	10-100 mm	Radar, satellites, WLAN data
Extremely High Frequency	EHF	30-300 GHz	1-10 mm	Radar, automotive, data

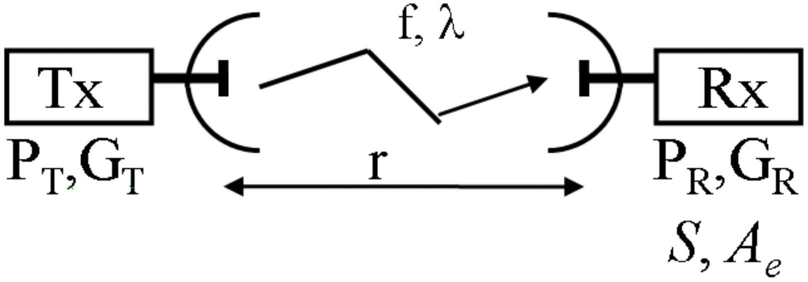
Frequency Bands

Designation for radar frequency band according to IEEE standards.

Letter Designation	Frequency Band (GHz)
L	1-2
S	2-4
C	4-8
X	8-12
Ku	12-18
K	18-27
Ka	27-40
V	40-75
W	75-110
mm	110-300

Friis Equation

- Friis Transmission Formula is the most fundamental equation of antenna theory.
- This equation relates transmit power, antenna gains, distance and wavelength to received power.



$$S = \frac{P_T G_T}{4\pi r^2}$$

S = power density

A_e = effective area

$$P_R = S.A_e = \frac{P_T G_T}{4\pi r^2} \cdot \frac{\lambda^2 G_R}{4\pi} \Rightarrow \frac{P_R}{P_T} = \left(\frac{\lambda}{4\pi r}\right)^2 G_T G_R$$

General Power Received

- The received signal power:

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

where G_r is the receiver antenna gain, G_t is the transmitter antenna gain, P_t is power transmitted and L is the propagation loss in the channel, i.e.,

$$L = L_P \, L_S \, L_F$$

- L_F: Fast fading
- L_S: Slow fading
- L_P: Path loss

Path Loss in 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.

This shows greater the $f_{c,}$ more is the loss.

Free Space Path Loss

$$L_p = \left(\frac{4\pi D}{\lambda}\right)^2$$

L_p = free space path loss
D = distance (km)
f = frequency (Hz)
λ = wavelength (m)

$$L_p(dB) = 32.4 + 20\log f_{(MHz)} + 20\log D_{(km)}$$

$$L_p(dB) = 92.4 + 20\log f_{(GHz)} + 20\log D_{(km)}$$

Propagation Techniques

A signal can be propagated in THREE (3) ways:

1. Ground-Wave Propagation

- Frequency < 2 MHz

2. Sky-Wave Propagation

- Frequency between 2 MHz and 30 MHz

3. Space-Wave (L.O.S)* Propagation

- Frequency > 30 MHz

*L.O.S = Line of Sight

References

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[2] Stutzman and Thiele, *Antenna Theory and Design*, John Wiley, 2012.

[3] T. A. Milligan, "Modern Antenna Design" John Wiley, 2nd edition, 2005.

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