# Wireless Communication Systems

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# Course Content

- Written exam (4p)
- Project (1p)

- 14 lectures (2h)

# Course Content

PART I

- Introduction, the electromagnetic wave
- Propagation
- Antennas

PART II

- Detection, Modulation
- Information theory, Channel models
- Channel Coding
- Multi-user systems

# Course Content

## PART III

- Cellular System
- GPS
- GSM
- WLAN
- Bluetooth

## PART IV

- Applications (Projects)

# Introduction

*The wireless telegraph is not difficult to understand. The ordinary telegraph is like a very long cat. You pull the tail in New York, and it meows in Los Angeles. The wireless is the same, only without the cat.*

*A. Einstein*

# Introduction

- The insight that energy could be transported without wires dates back to the late 19th century. J. C. Maxwell predicted it in 1850s
- Heinrich Hertz managed in 1888 to demonstrate a wireless energy transportation.
- Guillermo Marconi was the first that successfully applied the “hertzian waves” in communication (1895). 1901 he conducted the first trans-Atlantic radio communication.

# Path loss

- Since receivers where passive, all energy had to be generated at the transmitter (crystal receiver).
- The advent of the electron tube amplifier solved this problem.
- The receiver could be equipped with any amount of gain.
- The limiting factor became the noise.

# Noise

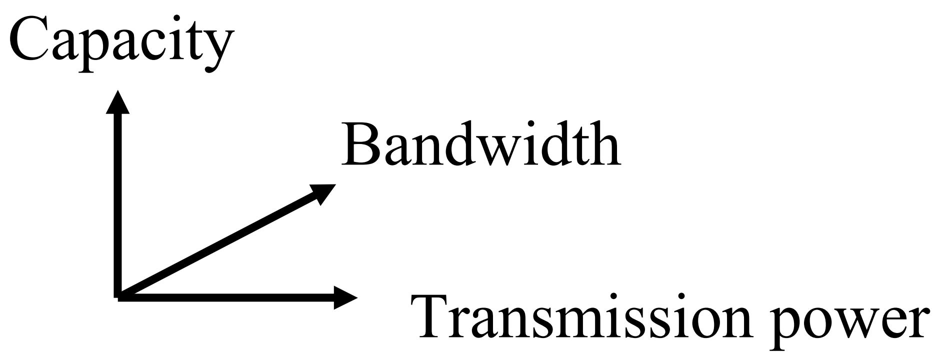
- Shannon deduced that the **noise** constituted a **fundamental limitation** to communication performance and constituted bounds on the amount of **information** that could be transferred reliably over different communication media.
- The **transistor** as an **amplifier** gave the radio industry a push forward. Small and cheap radio receivers and transmitters became possible.
- However using the transistor as a **switching element** made the real difference. **Digital technology** provides us with the opportunity to make full use of Shannon's early insight and enables us to tackle the noise as a limiting factor.

# Sharing the radio spectrum

- The number of wireless devices is now increasing rapidly. Since all devices utilise the same natural resource (the electromagnetic frequency spectrum) will the resource sharing problem become of paramount importance.
- Like most resource management problems in society this one has two sides: one political and one technical. It is a political decision to allocate different parts of the spectrum to different user categories. Furthermore, since radio waves propagates over national boundaries, this is an international problem, which is solved in international treaties.
- The technical include providing communication systems that are spectrally efficient, e.g., tolerate interference, systematic channel reuse…..

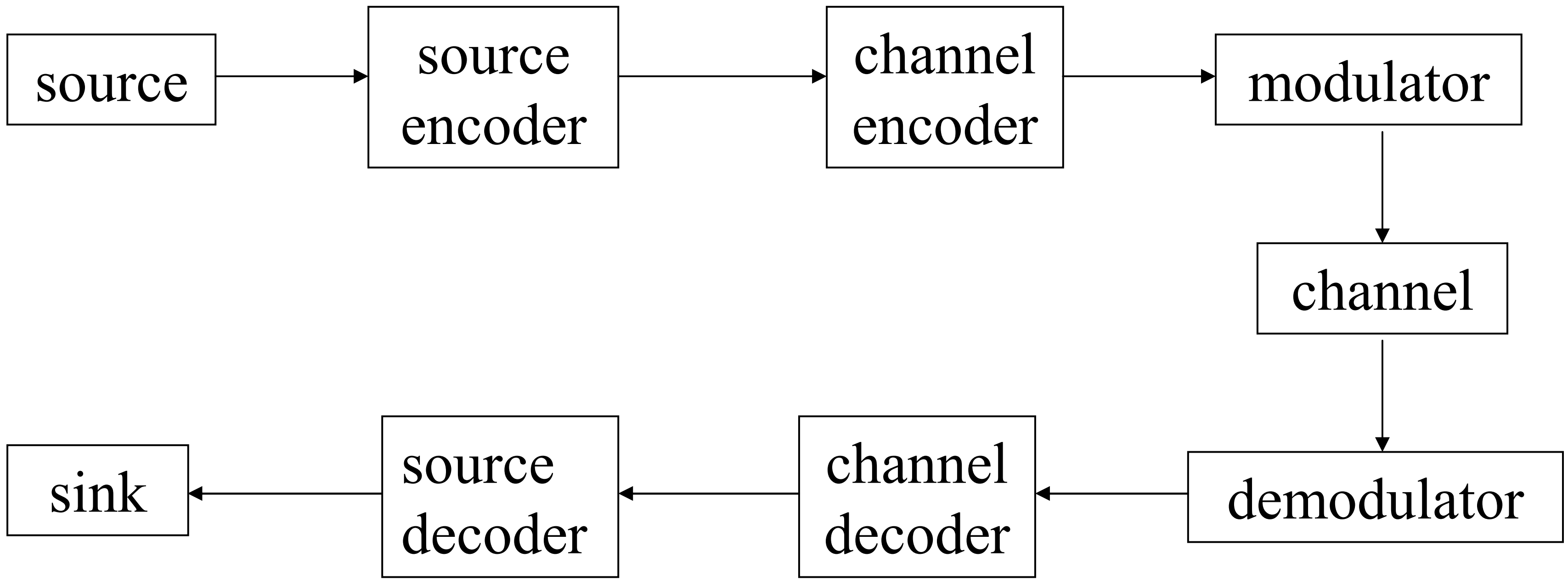
# The radio spectra as limited resource

There are two primary resources within the communication system, namely transmitted power and channel bandwidth. A goal for a system designer is to use these two resources as efficiently as possible, providing as much capacity as possible.




$$C = B\log_2\left(1+\frac{S}{N}\right)$$

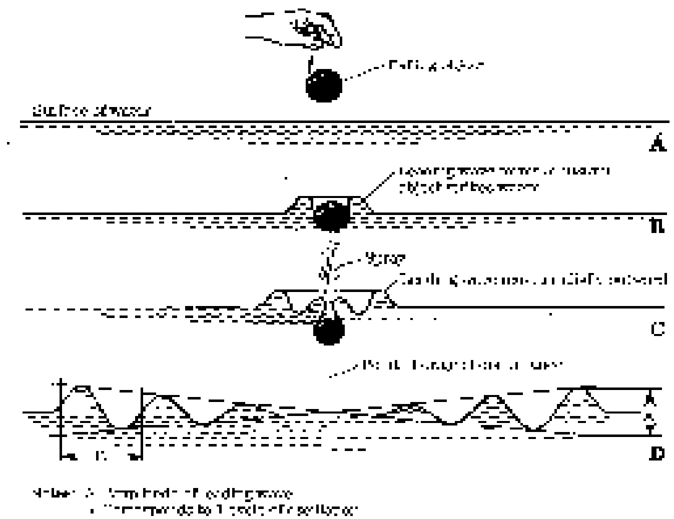
# Radio communication system

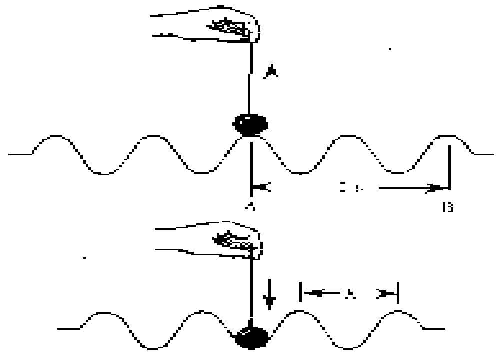


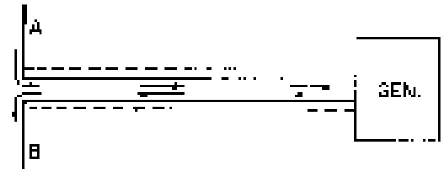
# The electromagnetic wave

*Radio communication is carried out by means of electromagnetic waves traveling through the earth's atmosphere, it is therefore important to understand the nature of these waves and their behavior in the propagation medium.*

# The electromagnetic wave








When the ball hits the water, it displaces water at its point of impact, and pushes a leading wall of water away from itself. The wave continues to propagate away from the ball until the energy is dissipated. The wave produced by a dropped ball is not continuous.

To make the analogy to radio waves more realistic, the wave must exist in a continuous fashion. A ball is dipped up and down in a cyclic manner, successively reinforcing new wave crests on each dip.

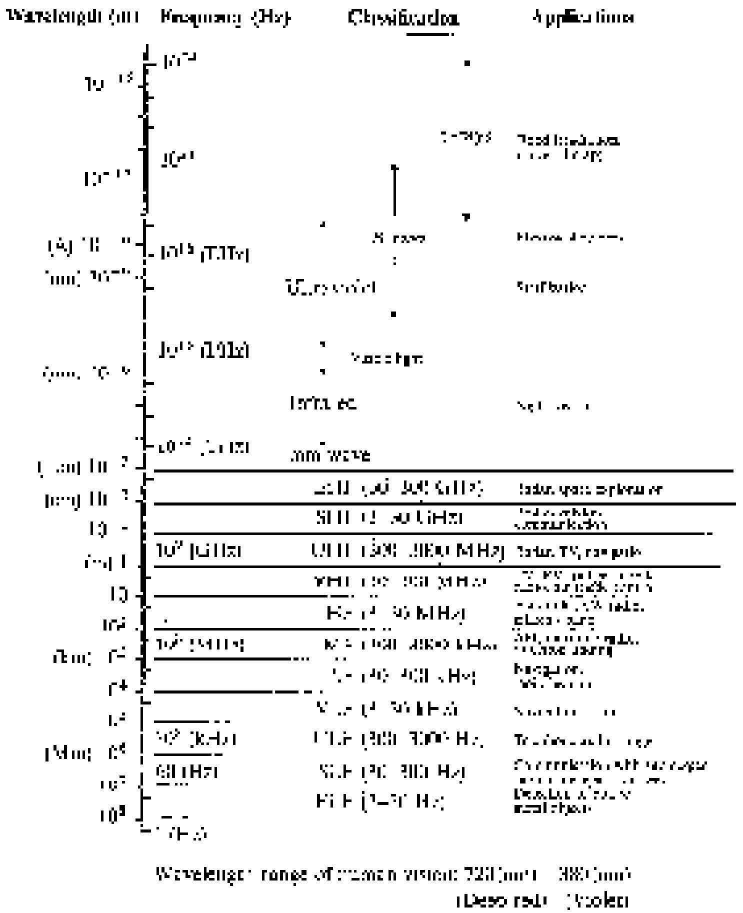
# The electromagnetic wave

- Waves used in radio communication may have frequencies from about 10000 Hz to several billion Hz.
- Suppose the frequency, ***f***, is 30 MHz (a low frequency compare with GHz used in many radio systems today), one period is completed in 1/30000000 seconds.
- The wave is traveling 300.000.000 meters per second, ***c***, so it will only travel 10 meters during the time of one complete period , ●.

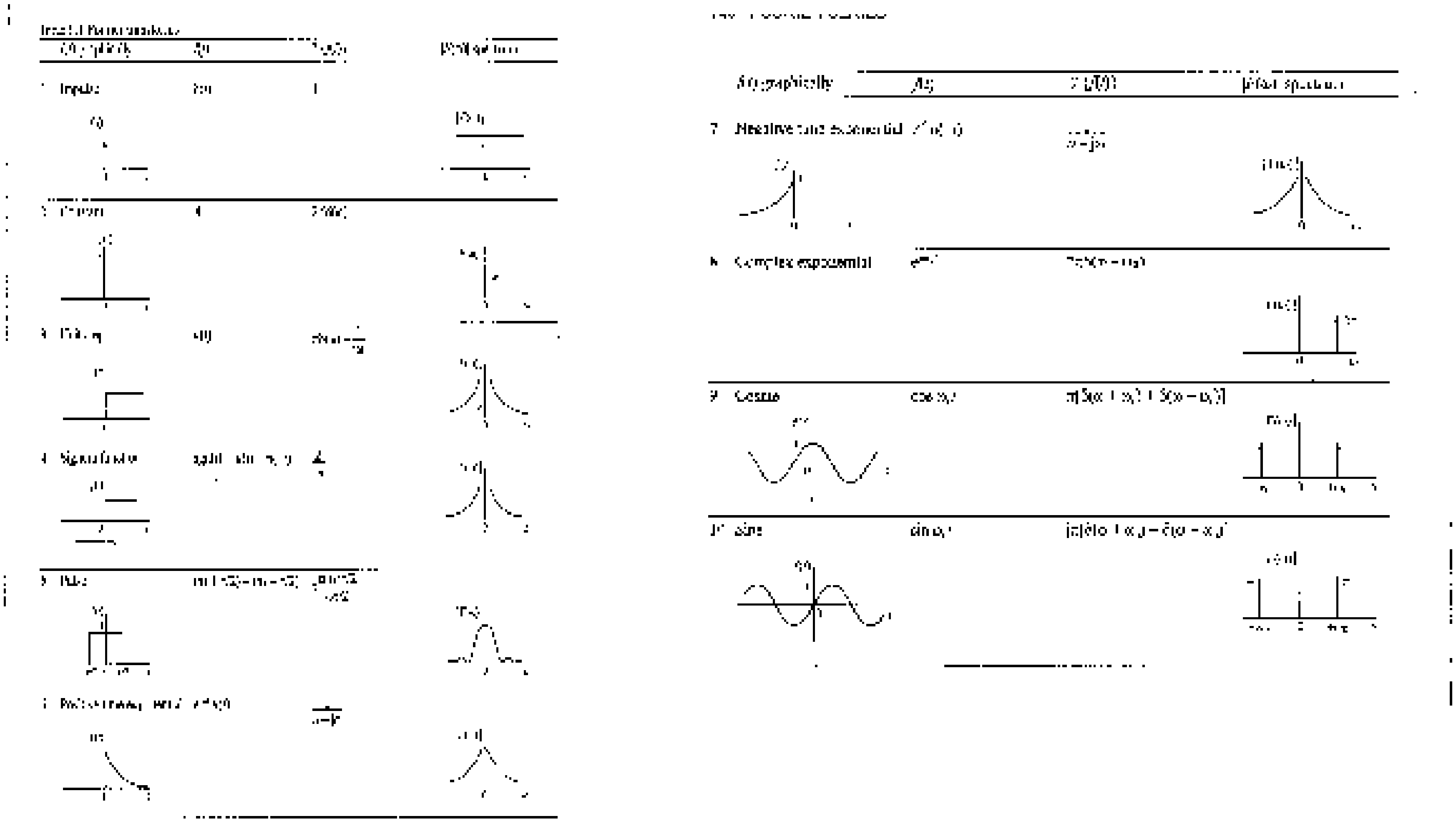
# The electormagnetic wave

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

| Frequency | Wavelength | Term |
|---|---|---|
| 300-3000 Hz | 1000-100 km | Extremely Low Frequency (ELF) |
| 3-30 kHz | 100-10 km | Very Low Frequency (VLF) |
| 30-300 kHz | 10-1 km | Low Frequency (LF) |
| 300-3000 kHz | 1000-100 m | Medium Frequency MF() |
| 3-30 MHz | 100-10 m | High Frequency (HF) |
| 30-300 MHz | 10-1 m | Very High Frequency (VHF) |
| 300-3000 MHz | 100-10 cm | Ultra High Frequency (UHF) |
| 3-30 GHz | 10-1 cm | Super High Fequency (SHF) |
| 30-300 GHz | 10-1 mm | Extremly High Frequency (EHF) |



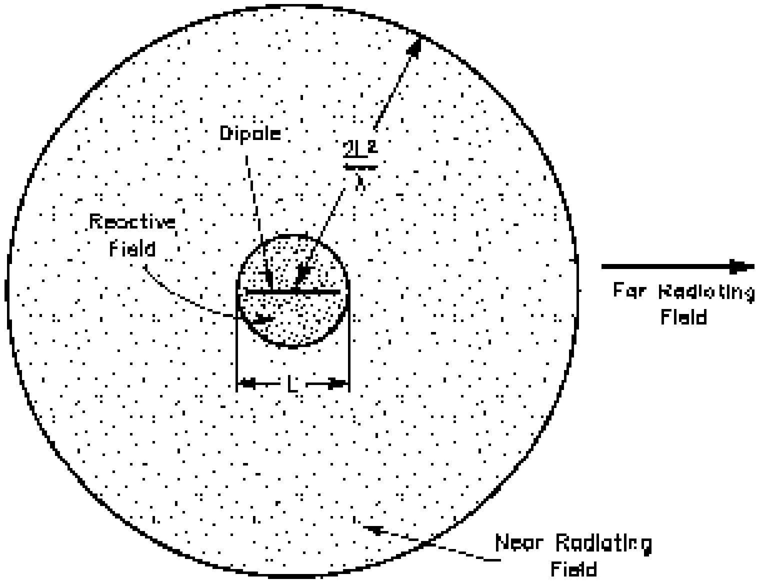
# Time versus frequency



# The electromagnetic wave

The electrical force, **F**, acting on a charge ***q*** can be described by two fields, called **E** and **B**, and the velocity ***v*** of charge ***q***.

$$\mathbf{F} = q(\mathbf{E} + \mathbf{V} \times \mathbf{B})$$




Electric field E is given by:

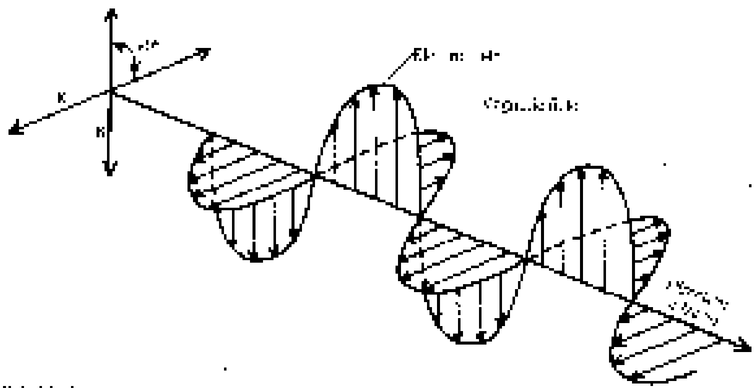
$$\mathbf{E} = \frac{-q}{4\pi\varepsilon_0}\left[\frac{\mathbf{e_r}'}{r'^2} + \frac{r'}{c}\frac{d}{dt}\left(\frac{\mathbf{e_r}'}{r'^2}\right) + \frac{1}{c^2}\frac{d^2}{dt^2}\mathbf{e_r}'\right]$$

$$\mathbf{E} = \frac{-q}{4\pi\varepsilon_0 c^2}\frac{d^2\mathbf{e_r}'}{dt^2}$$

$$E_x(t) = \frac{-q}{4\pi\varepsilon_0 c^2 r}a_x\left(t - \frac{r}{c}\right)$$

# The electromagnetic wave

A radio wave far enough from its source is called a flat wave.



The electromagnetic field consists of an electrical field, varying in space and time. Let the vector E(x,y,z,t) describe this field. In addition we have a corresponding magnetic field H(x,y,z,t), these two fields are orthogonal.

# The electromagnetic wave

- A measurement of the strength of the wave at a distance from the transmitting antenna is its ***field intensity***, which is synonymous with ***field strength***.
- The strength of a wave is measured as the voltage between two points lying on an electrical line of force in the plane of the wave front.
- The standard measure for field intensity is the voltage developed in a wire that is 1 meter long, expressed as ***voltage per meter***.
- The voltage in a wave is usually low, so the measurement is made in ***millivolts*** or ***microvolts***.

# The electromagnetic wave

The field propagates with the speed of light and transports energy in a direction perpendicular to both **E** and **H**. Poyntings vector describes this energy flow:

$$\mathbf{P} = \mathbf{E} \times \mathbf{H}$$

The average magnitude (length) of Poyntings vector, **P**, is denoted the intensity or the ***power density*** of this field. For a sinusoidal field this becomes:

$$S = \frac{1}{2}\left|\mathbf{P}\right| = \frac{1}{2}\left|\mathbf{E}\right| \cdot \left|\mathbf{H}\right| \qquad [\mathrm{W/m^2}]$$

The relationship between power density and field strength is given in the energy equations. The energy $dW$ in a volume element $dV$ in free space carried by the electrical and magnetical field is given by:

$$dW_E = \frac{1}{2}\varepsilon_0 \left|\mathbf{E}\right|^2 dV \qquad\qquad dW_H = \frac{1}{2}\mu_0 \left|\mathbf{H}\right|^2 dV$$

# The electromagnetic wave

Where $\varepsilon_0$ and $\mu_0$ are the constant of permittivity and permeability for the medium respectively, in our case vacuum.

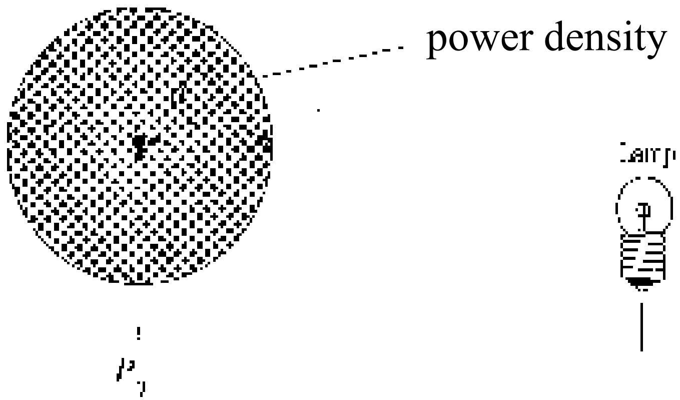
In free space both fields carry the same amount of energy, such that:

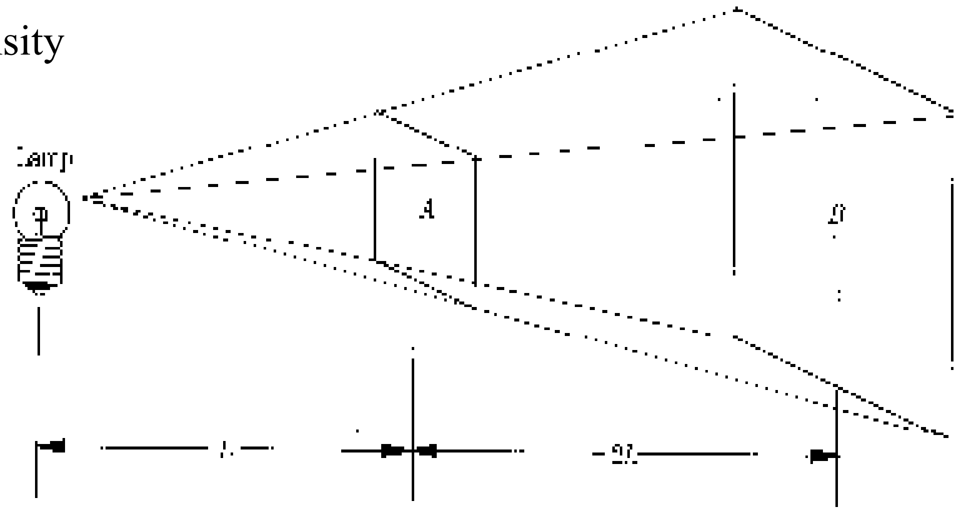
$$\varepsilon_0 |\mathbf{E}|^2 = \mu_0 |\mathbf{H}|^2$$

The impedance of vacuum $Z_0$ can then be defined as:

$$Z_0 = \frac{|\mathbf{E}|}{|\mathbf{H}|} = \sqrt{\frac{\mu_0}{\varepsilon_0}} \approx 120\pi \approx 377 \qquad \text{[ohm]}$$

# The electromagnetic wave



Isotropic radiation

The power density on the sphere (and thus at the receiving antenna) can therefore be computed as:

$$S_r = \frac{P_t}{4\pi r^2}$$

# Polarization

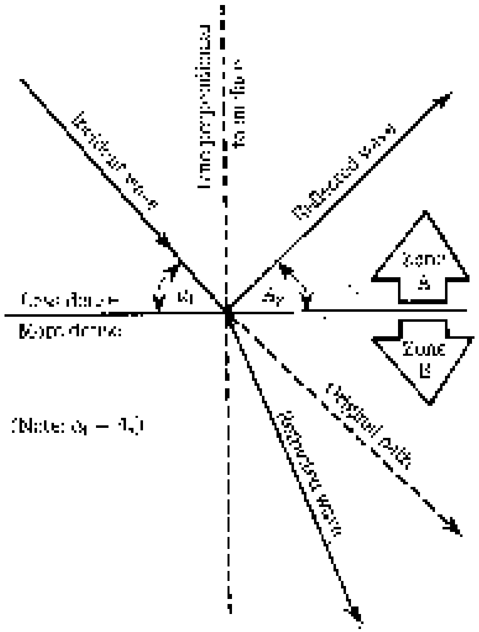
# Wave propagation phenomena

# Wave propagation phenomena

- Reflection
- Refraction
- Diffraction
- Scattering

*Radio propagation is nearly always a mix of these phenomena, and it may not be easy to separate them in real radio systems.*

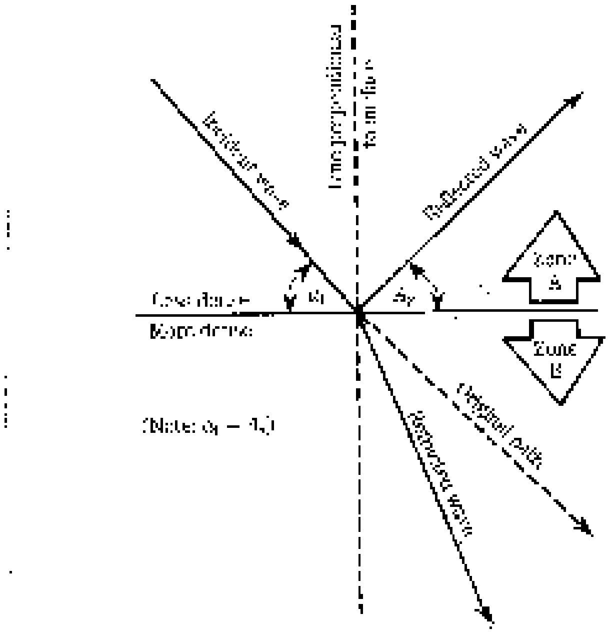
# Wave propagation phenomena




**Reflection** occurs when a wave strikes a denser reflective medium (often an object with large dimension compared with the wavelength). The incident wave strikes the interface between less dense and more dense medium at a certain angle of incidence, and is reflected at exactly the same angle.

Depending on the wave length (frequency), radio waves may be reflected by buildings, trees, vehicles, the ground, water, ionized layers, or at boundaries between air masses having different temperature and moisture content.

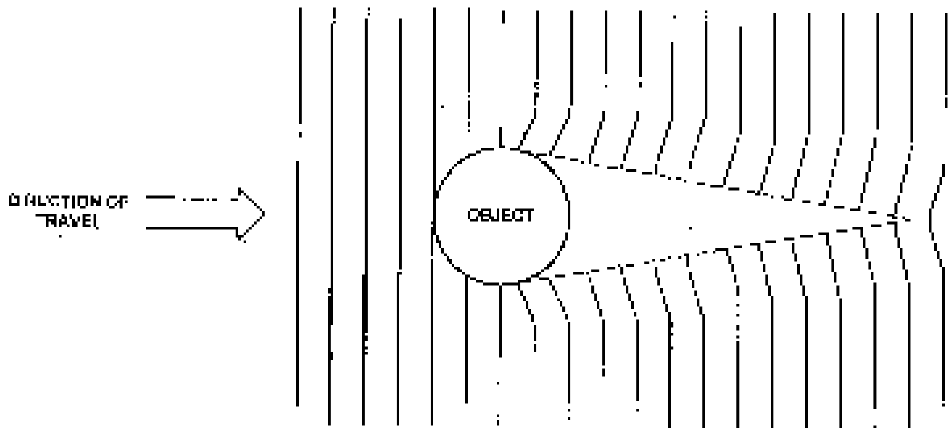
# Wave propagation phenomena




**Refraction** occurs when the incident wave enters a region of different density, and thereby undergoes both a velocity change and a directional change.

The appearance of bending of a straight stick, where it enters water at an angle, is an example of light refraction, known to us all.

# Wave propagation phenomena

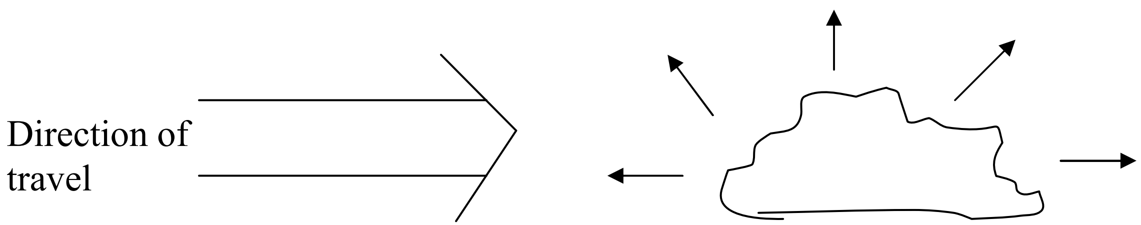



**Diffraction** occurs when an advancing wave front encounters an opaque object. The shadow behind the building is not perpendicular to the wave, but takes a cone shape as waves bend around the object.

The ***diffraction zone*** between the ***shadow zone*** and the ***direct propagation zone*** is a region of weak signal strength. In practical situations, signal strength in the shadow zone rarely reach zero. A certain amount of reflected signals scattered from other sources will fill in the shadow a little bit. The degree of diffraction effect seen in any given case is a function of the wavelength of the signal, the size of the object and its electromagnetic properties.

# Wave propagation phenomena

- Scattering occurs when the radio wave travels through a medium containing a lot of small (compared to the wavelength) objects, which influences the propagation.
- Scattered waves are produced by irregularities in the media or rough surfaces (e.g. urban environment in mobile communication)



# Four propagation paths

- Surface wave
- Space wave
- Tropospheric
- Ionospheric

Ground waves

# Ground wave

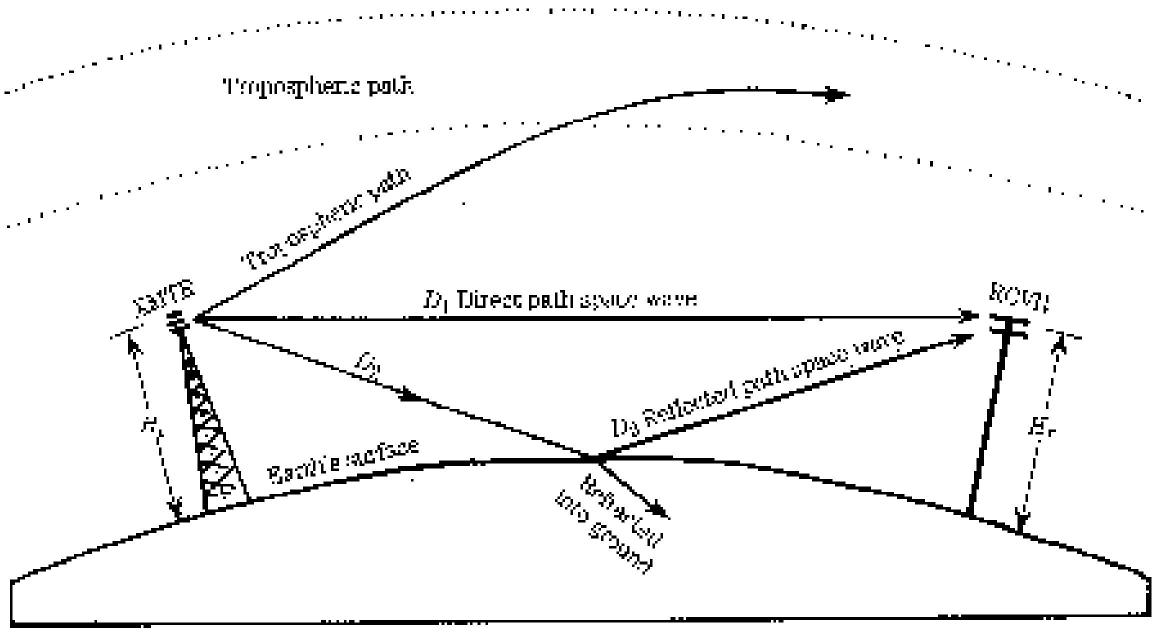
- The ***space wave(direct wave)*** and the ***surface wave*** are both ground waves.
- ***Surface wave*** travels in direct contact with the earth's surface and it suffers a severe frequency dependent attenuation caused by absorption into the ground.
- The ***space wave*** is radiated from an antenna many wavelengths above surface; VHF, UHF and microwave signals are usually space waves.

# Surface wave

- The ***surface wave*** is subject to the same attenuation factors as a space wave, but in addition it also suffers from ground losses.
- These losses are caused by ***ohmic resistive losses*** in the conductive earth. The signal heats up the ground.
- Surface wave attenuation is a ***function of frequency***, and it increases rapidly as frequency increases.
- Horizontally polarized waves are not often used for surface wave communication because the earth tends to short-circuit the E field component.
- In very low frequency band(<300 kHz), ground losses are small, so medium distance or in some cases long distance communication is possible (Grimeton approx. 17 kHz).

# Space wave

There are at least two components of the space wave: one directed and one reflected.




If both of these components arrive at the receiving antenna, they will add algebraically to either increase or decrease signal strength.

# Multipath effect

- There is always a phase shift between the two components because the two signal paths have different length.
- A phase shift of an odd number of half wavelengths causes the components to add, increasing signal strength (*constructive self interference*).
- A phase shift of an even number of half wavelength causes the components to subtracts, thus reducing signal strength (*destructive self interference*).
- Phase shifts other than half wave length add or subtract according to relative phase and amplitude.

# Multipath effect

- Most familiar multipath phenomena is ***ghosting*** in ”off the air” analog television reception.
- In mobile communications, multipath phenomena are responsible for reception ***dead zones***. A dead zone exists when destructive interference between direct and reflected waves drastically reduces the signal strength.
- ***Picket fencing*** occurs as a mobile unit moves through successive dead zones and signal enhancement zones, and it sounds like a series of short noise bursts.

# Radio Horizon

- At higher frequency (VHF, UHF and microwaves), the space wave is limited to so called line of sight distance.
- The horizon is theoretically the limit of communication distance, but the radio horizon is actually about 15 percent farther than the optical horizon.
- The phenomena is caused by refractive bending in the atmosphere around the curvature of the earth