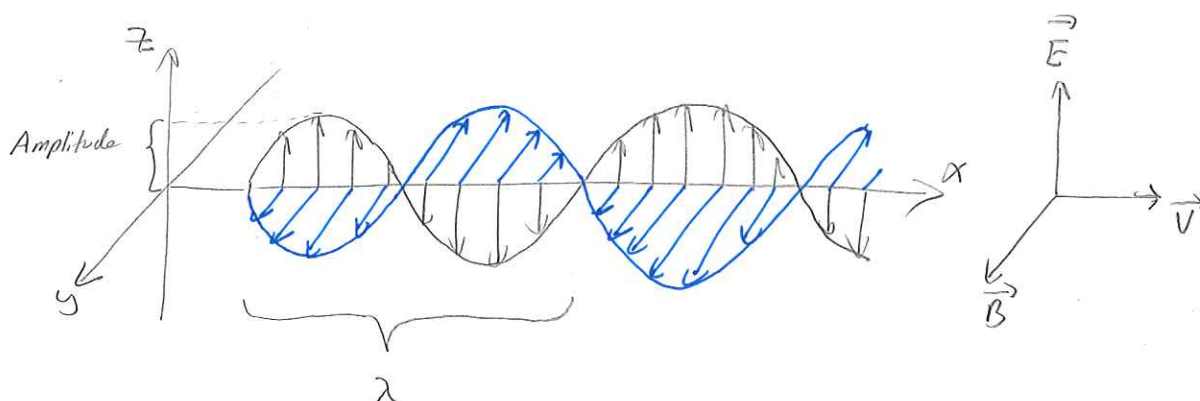


## Exercise

Discuss for 3 minutes: What are radio waves and how do they propagate?

## Electromagnetic waves and propagation



Wavelength: The distance covering one full period [m]

Amplitude: The height of a crest or trough

Frequency: The number of wavelengths that pass a given point in a second [Hz]

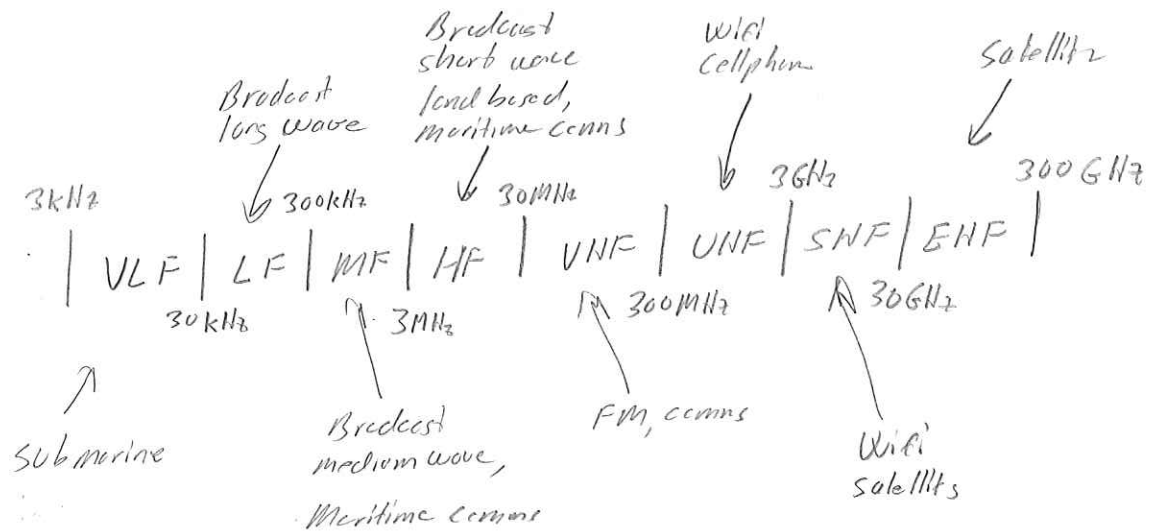
Propagation velocity:  $v = f \cdot \lambda$

In vacuum,  $v = c = 3 \cdot 10^8 \frac{m}{s}$

## Polarization

Vertical, horizontal, CW and CCW circular

## Radio frequency spectrum



### Higher Frequency properties:

- Higher bandwidth
- More attenuation from refractions and reflections

### Typical drone spectrum

35 MHz, 433 MHz, 868 MHz, 2,4 GHz, 5,8 GHz

### Exercise

- What are the corresponding wavelengths?
- What are they used for in drone technology?
- What other typical uses?

## Decibel

Decibel is a scale based on the logarithm using 10 as base. It is suitable for comparing values of different orders of magnitude.

For Voltage and Current the amplification in dB is

$$\text{dB} = 20 \cdot \log_{10} \frac{V_1}{V_2}$$

$$\text{dB} = 20 \cdot \log_{10} \frac{I_1}{I_2}$$

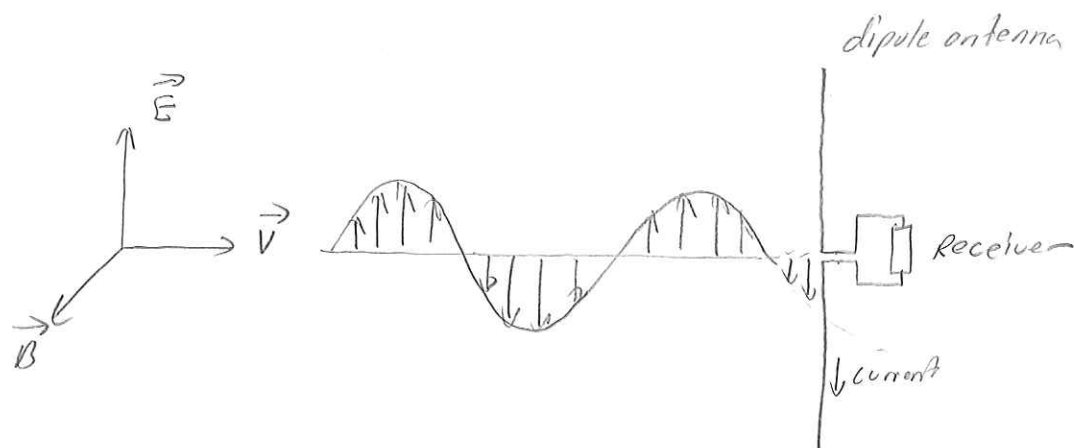
For power the amplification in dB is

$$\text{dB} = 10 \cdot \log_{10} \frac{P_1}{P_2}$$

Doubling voltage or current thus corresponds to an increase of 6 dB

Doubling the power corresponds to an increase of 3 dB

## Antennas



The electric field of the incoming radio wave pushes the electrons in the antenna back and forth. The dipole ends are charged alternately.

The dipole is  $\frac{\lambda}{2}$  long, the oscillating field induces standing waves of voltage and current in the rods.

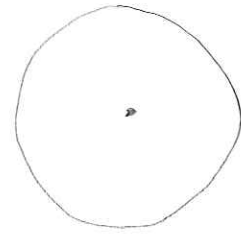
The oscillating currents flow down the transmission line and through the receiver.

## Isotropic antenna

Theoretical point shape

Spherical propagation

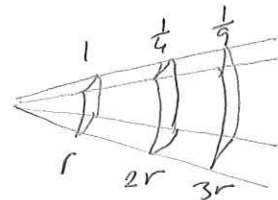
sphere in 3d  
↓



## Inverse Square Law

The energy flow  $\left[\frac{W}{m^2}\right]$  is proportional to  $\frac{1}{d^2}$  where  $d$  is the distance from the source

$$A_{\text{area}} = 4\pi r^2$$



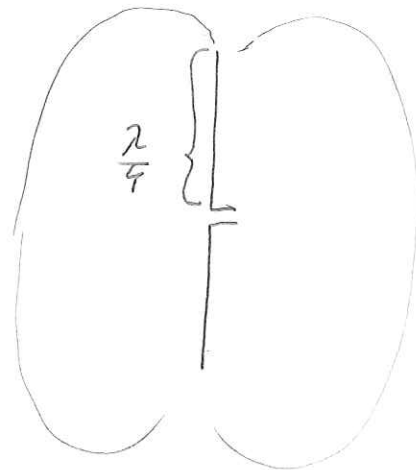
## Antenna gain

Modification of the antenna radiation pattern, typically measured in dBi or dBd

donut shaped in 3d  
↓

## Dipole antenna

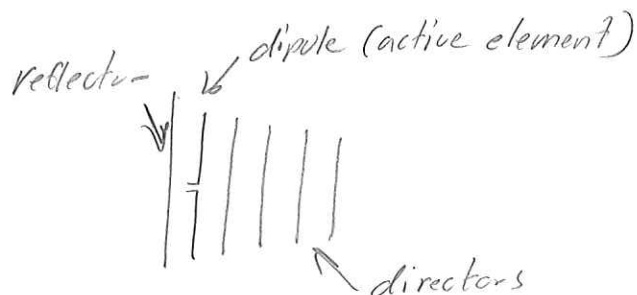
Gain 2.15 dBi  $\approx$  1 dBd



## Ground Plane



## Yagi-Uda



## Reciprocity

The gain of the antenna when transmitting is equal to the gain of the antenna when receiving