# Foundations of electromagnetic wave propagation

## Introduction

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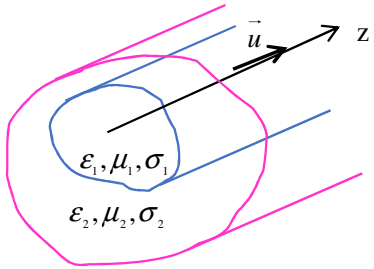
# Propagation of an electromagnetic signal, a wave : characteristic parameter definition

## ‘Microwaves’ : definition et applications

- telecom
- antennas
- spatial communications
- radar

## Course outlines

## Propagation of an electromagnetic signal, a wave : characteristic parameter definition




Section of the line homogeneous along z axis

Each medium considered homogeneous in this introduction

The signal transmitted along the line is written :

$$e(z,t) = \mathrm{E}\cos(\omega t - \beta z)$$

E is the signal intensity

$\omega$ is the angular frequency. $\omega = 2\pi f$, $\boldsymbol{f}$ **is the signal frequency**

$\boldsymbol{T = 2\pi/\omega = 1/f}$ **is the time period**

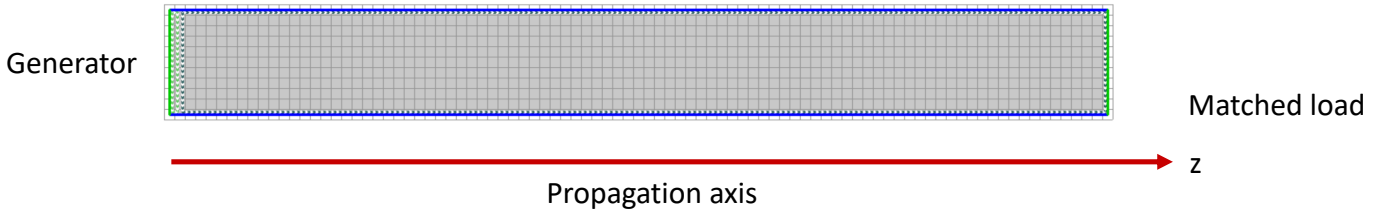
$\boldsymbol{\beta}$ **is the propagation constant**

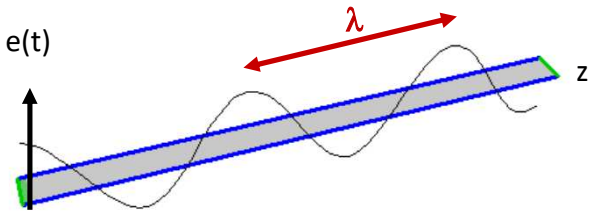
$\boldsymbol{\lambda = 2\pi/\beta}$ **is the spatial period**

## Propagation of an electromagnetic signal, a wave : characteristic parameter definition

$$e(z,t) = \mathrm{Ecos}(\omega t - \beta z) = \mathrm{Ecos}\left[\omega\left(t - \frac{1}{\omega/\beta} z\right)\right]$$

$v = \omega/\beta$ is the phase velocity, and $\lambda = v/f$

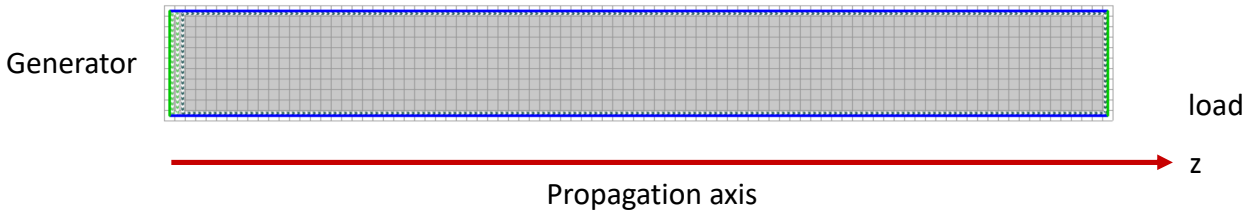


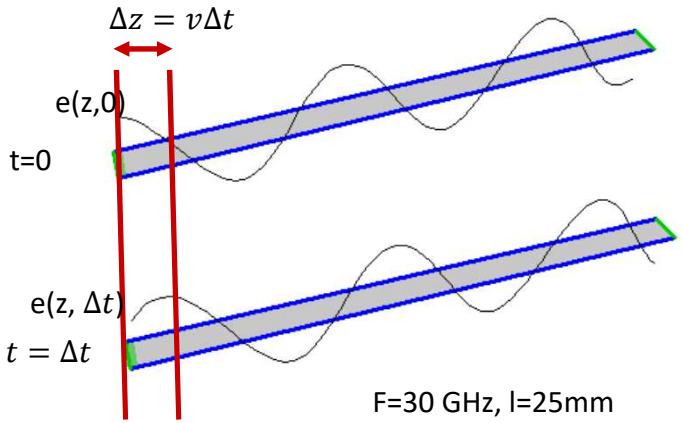




For v=c=$3.10^8$ m/s

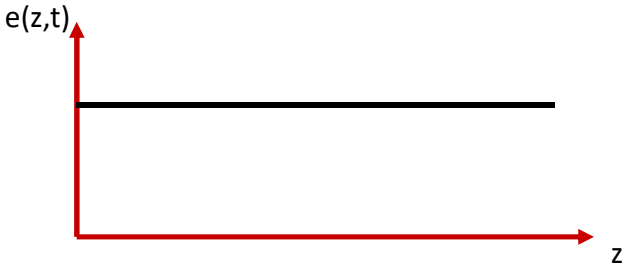
$\lambda = 10$ cm at 3 GHz
$\lambda = 10$ mm at 30 GHz

## Propagation of an electromagnetic signal, a wave : characteristic parameter definition




F=30 GHz, l=25mm




F=30 MHz, l=25mm

# 'Microwaves' : definition et applications

## ✓ Definition

**Micro**wave :

✓ Frequency domain between short-rang radio and infrared wave in the more general definition

✓ Centimetric and millimetric wavelengthes (100 cm to 1 mm, 300 MHz to 300 GHz) in a more narrow definition

✓ Frequency space ranging from 0.9 GHz to 150 GHz in common usage

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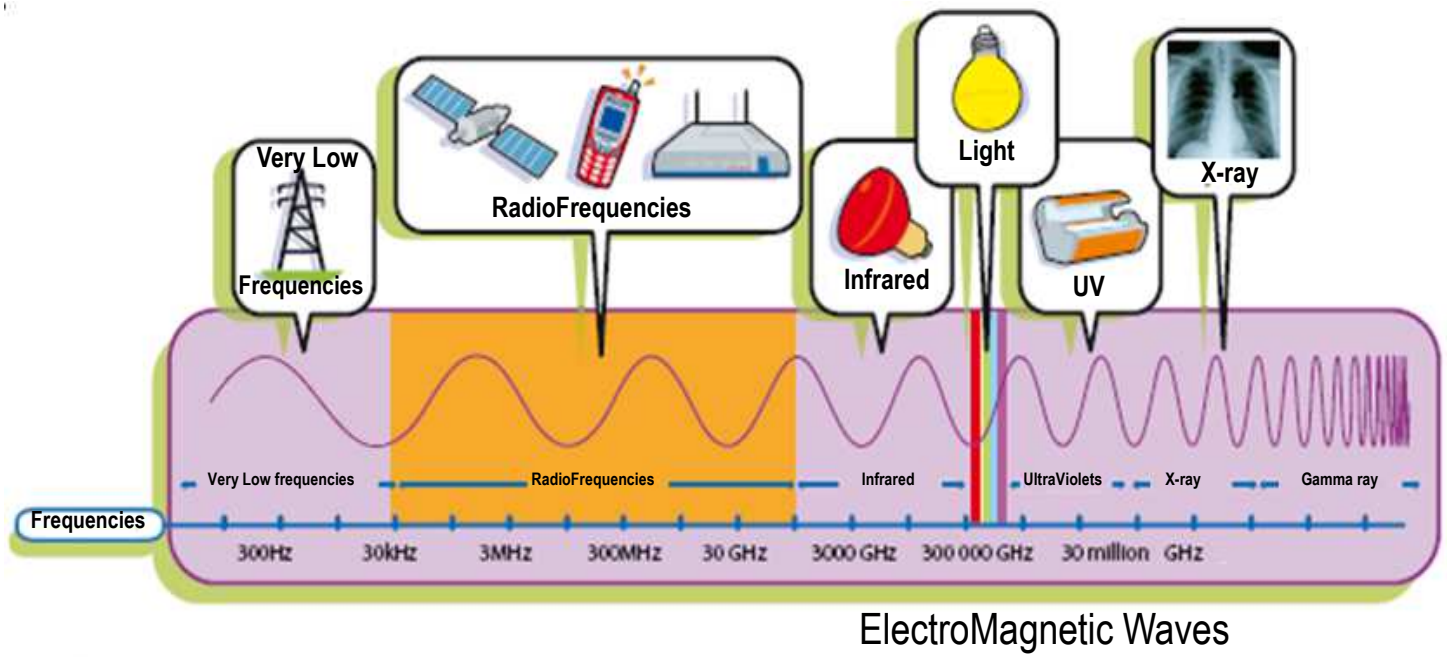
**What is not modified with the frequency level**: physical laws, Maxwell equations

**Why microwaves require specific learning:**

The circuits dimensions are in the range of the wavelength in this frequency domain : a line, with specified length and width for instance, can exhibit an inductance, a capacitance, a short circuit, or an open circuit behaviour :
**component, circuit and system technologies are specific to this frequency domain.**

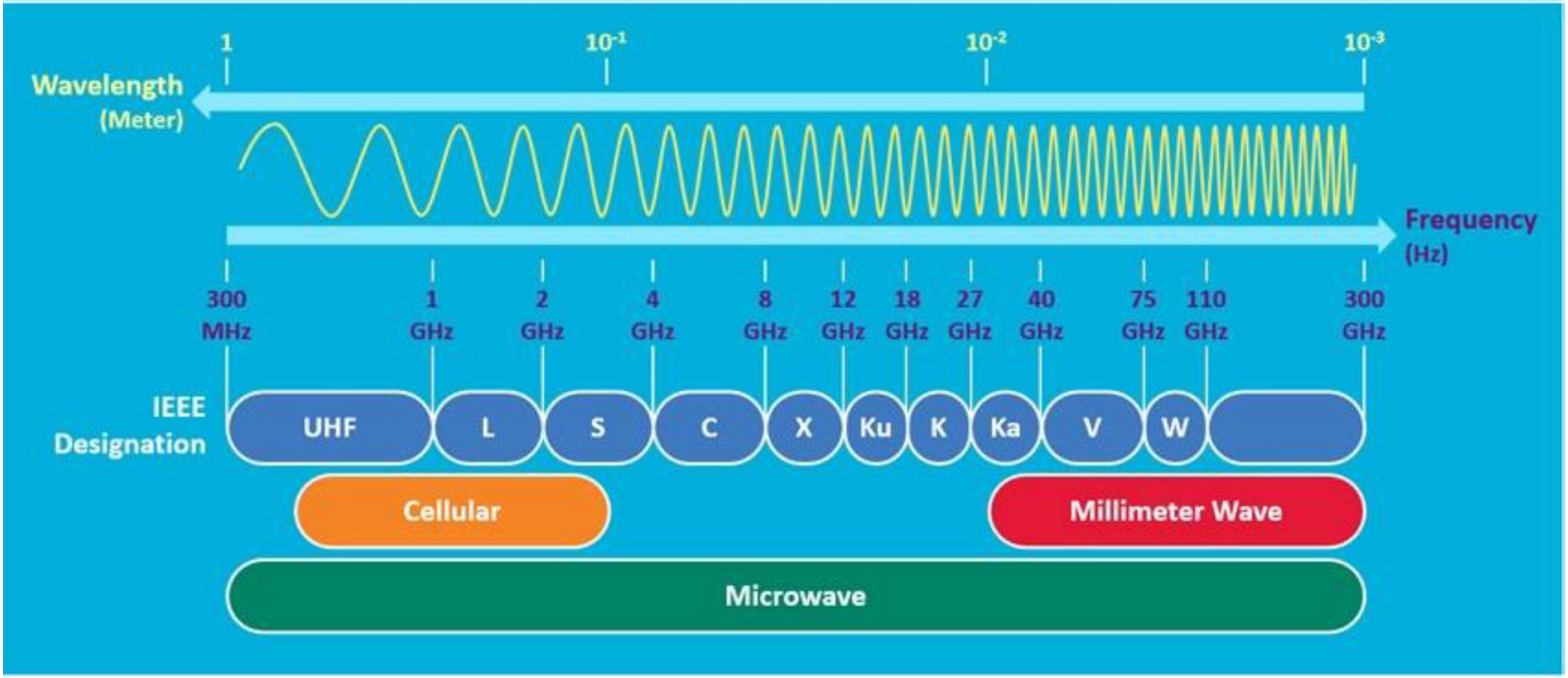
✓ **The radiation of components increases with the frequency,** wich generate couplings between these components.
**Antenna dimensions** is in relation with he wavelength.
✓ Transistors have the capability to generate power in the microwave bandwidth, and not really above
✓ Measurement technics are in a large part specific to this frequency domain.

# 'Microwaves' : definition et applications



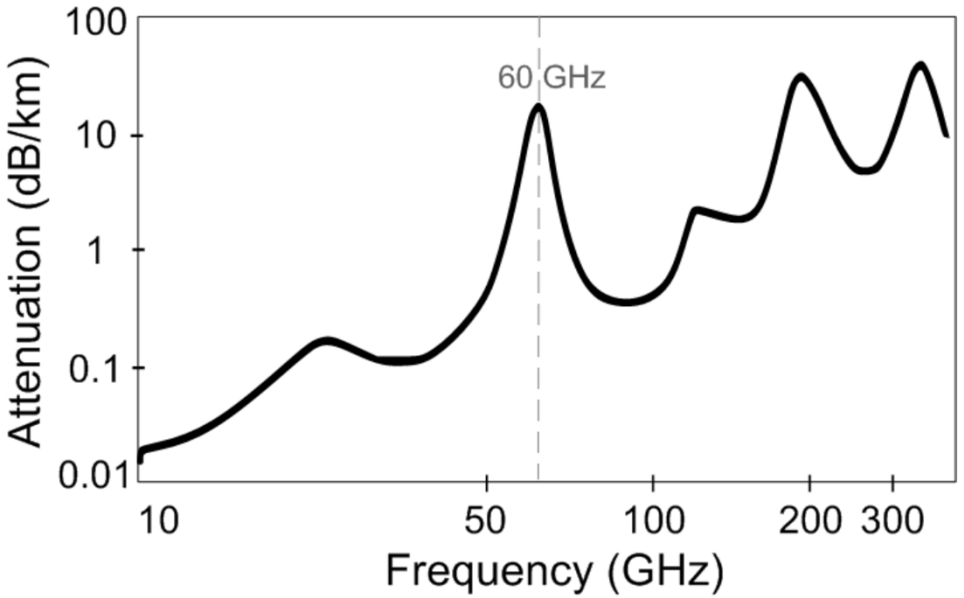

ElectroMagnetic Waves

# Microwave spectrum

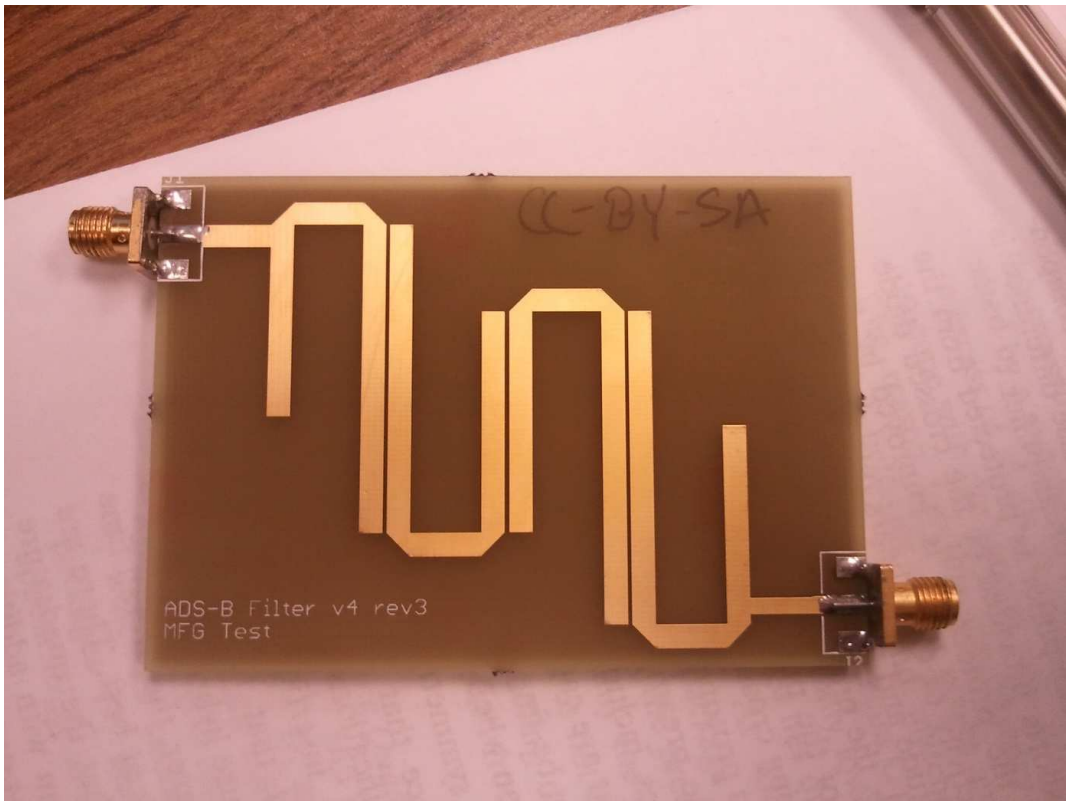


# 'Microwaves' : definition et applications

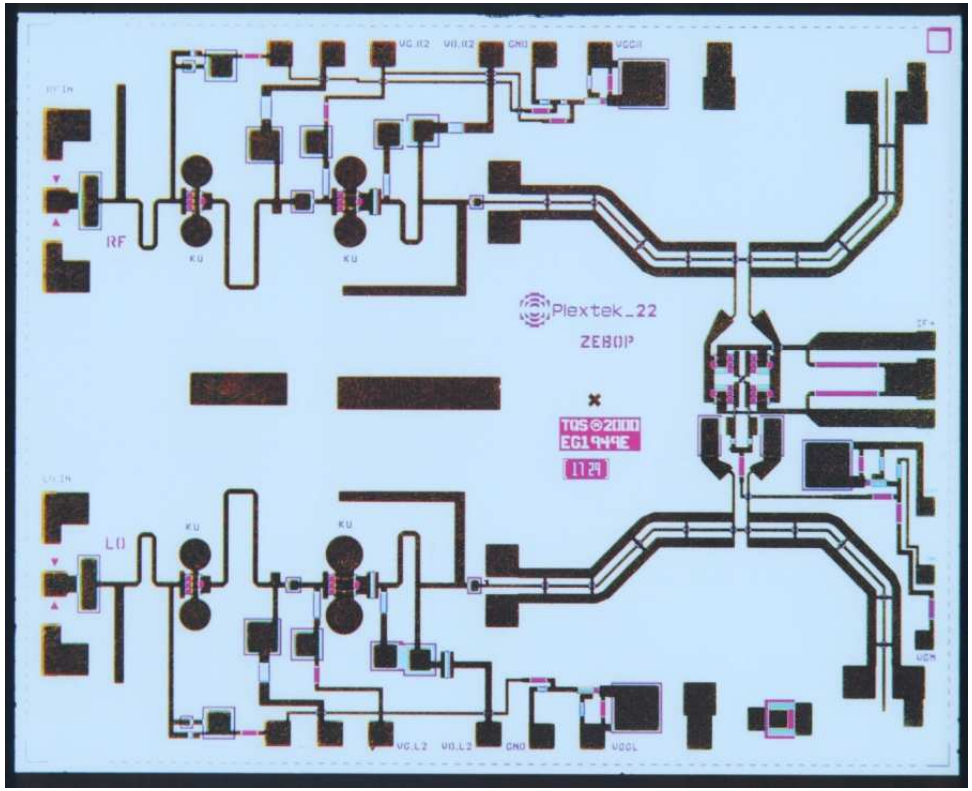
Absorbing properties for wireless communications



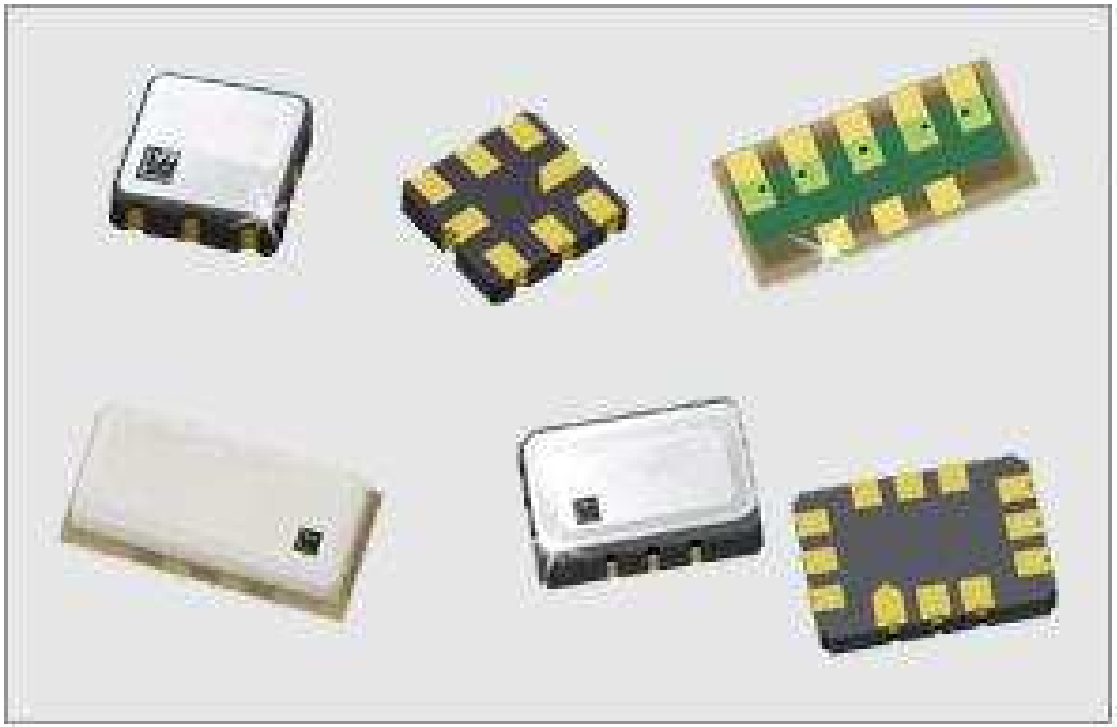
# Microwave distributed planar circuit



# MMIC



# Surface mounted components for printed circuit boards



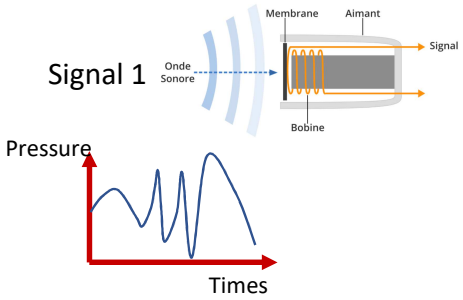
# Microwave subsystem

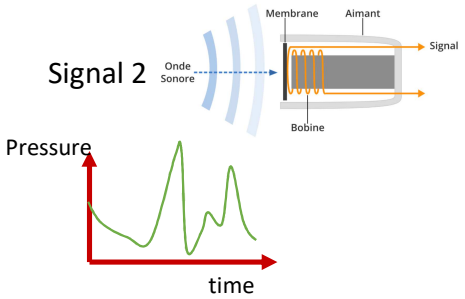
# Microwaves : définition et applications / telecom

## Why using this frequency domain?

✓ Data rate increase (voice, vidéo, internet, connected objects (IOT), …) with the frequency

**Illustration :** voice transmission between 2 phones



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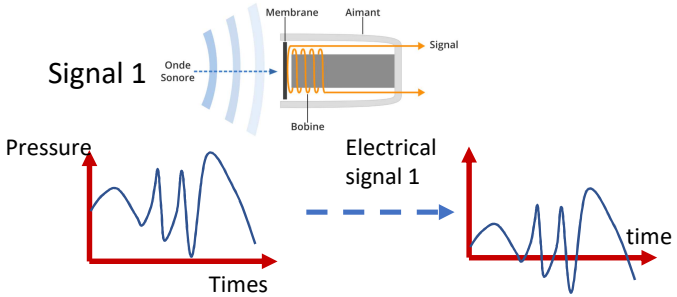


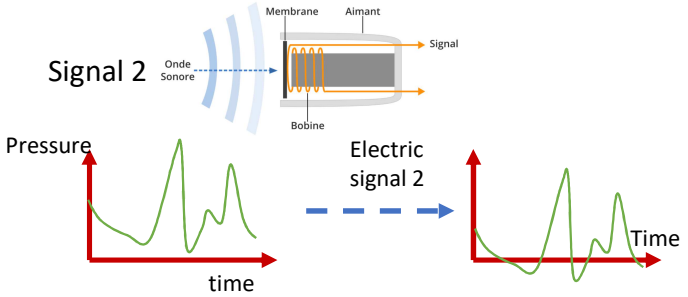

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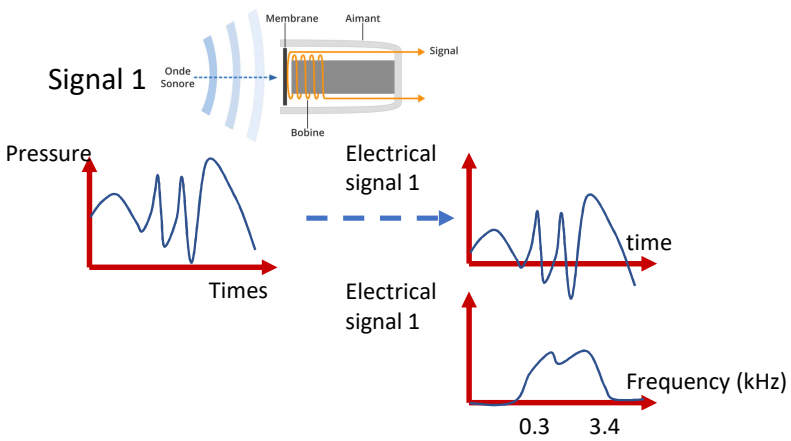


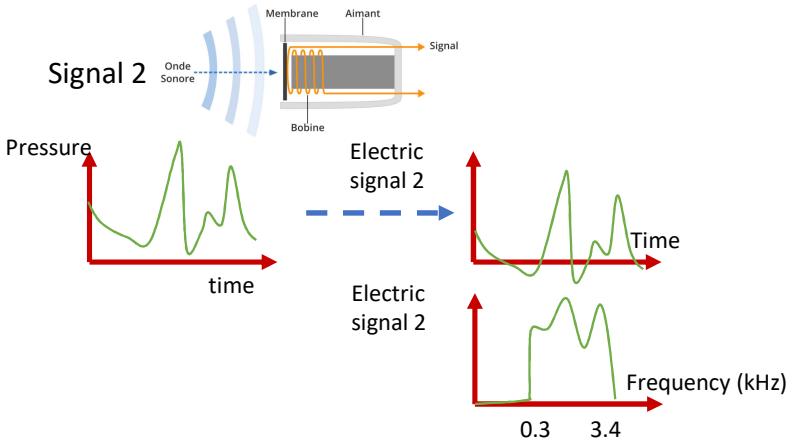

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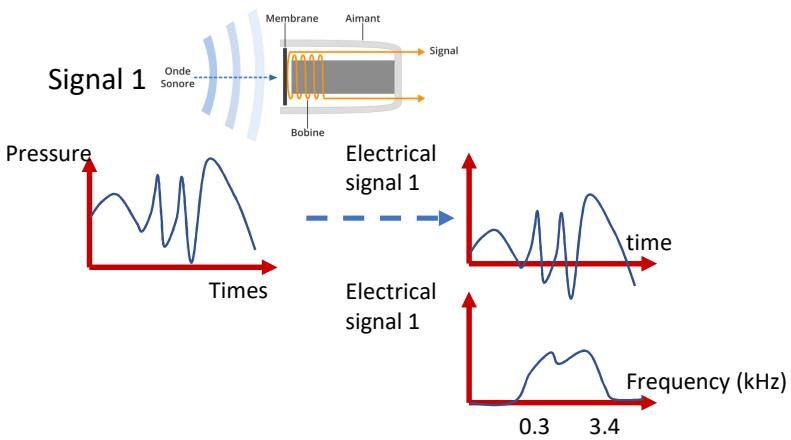
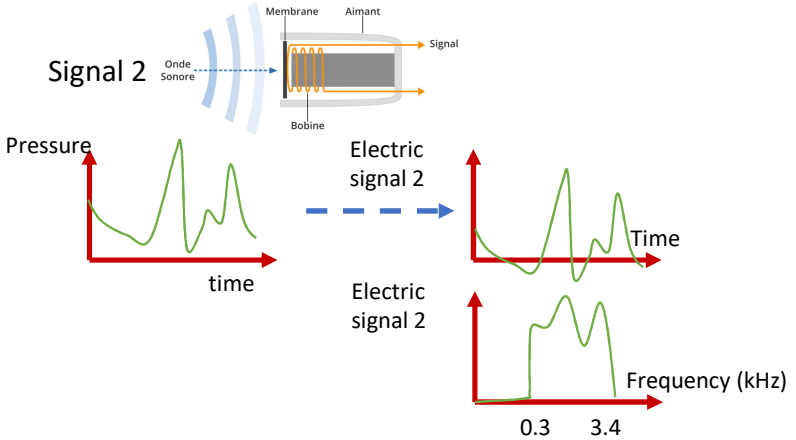
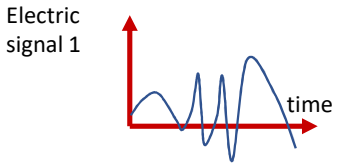



How can we transmit the signals 1 and 2 on a same line, though a same antenna, and at the end share them to send them to the right recipient?

# Microwaves : définition et applications / telecom

Signal digitizing :



# Microwaves : définition et applications / telecom

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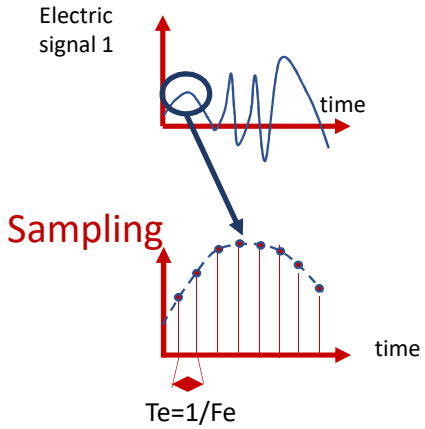


Sampling

Fe sampling frequency>2Fmax signal

# Microwaves : définition et applications / telecom

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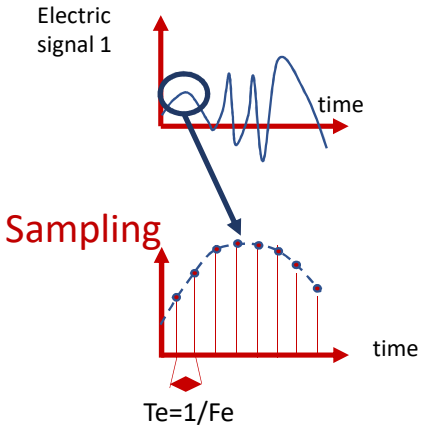
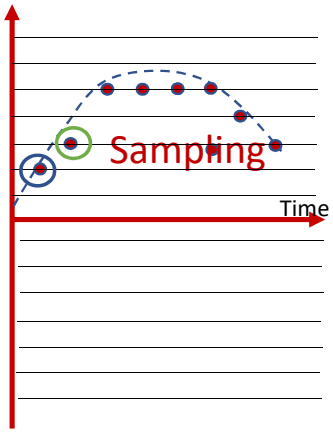



Fe sampling frequency>2Fmax signal

Quantification : choice of a number of bits, here 4 (16 levels)



# Microwaves : définition et applications / telecom

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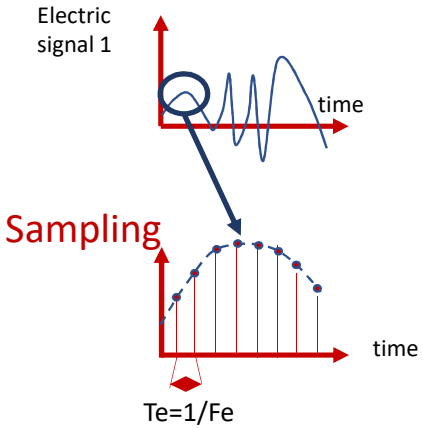


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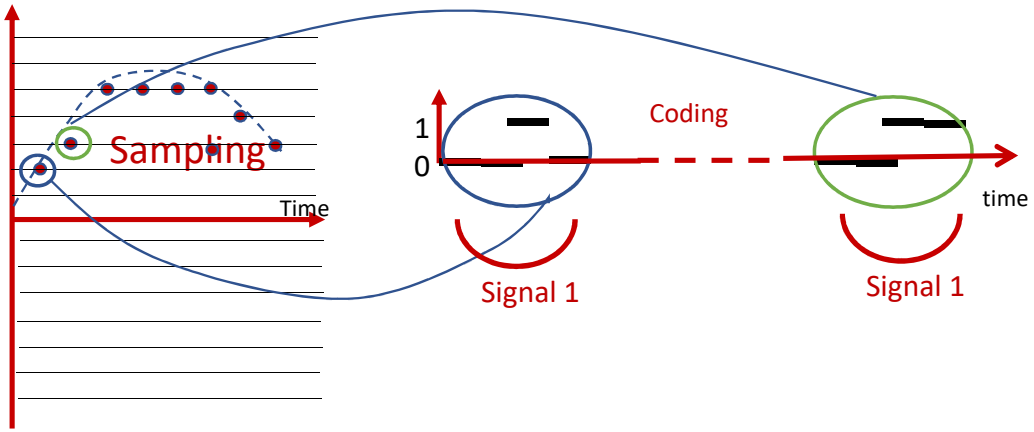

# Microwaves : définition et applications / telecom

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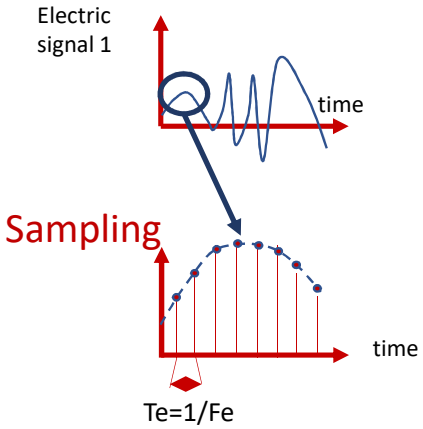


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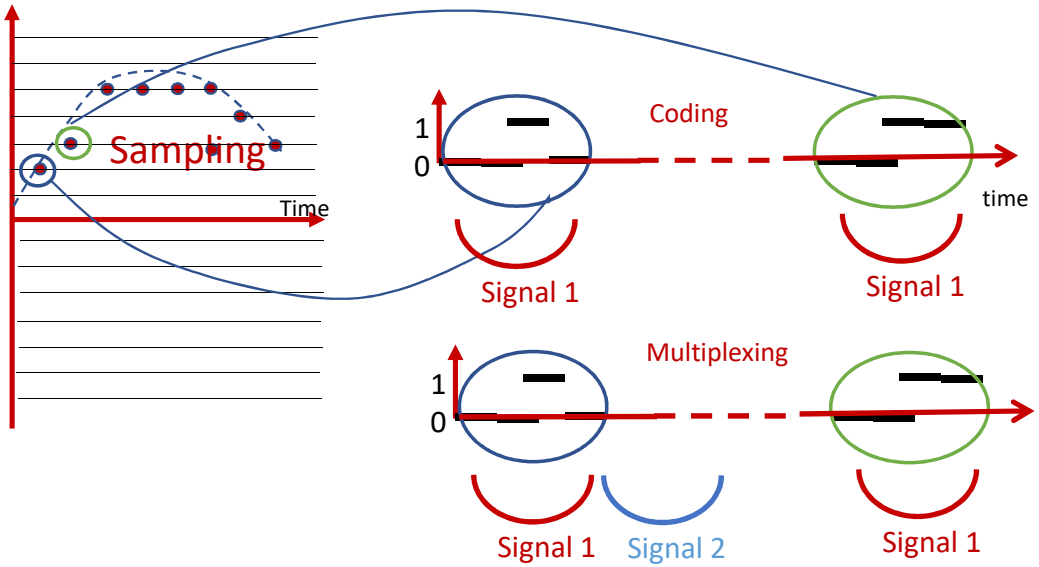
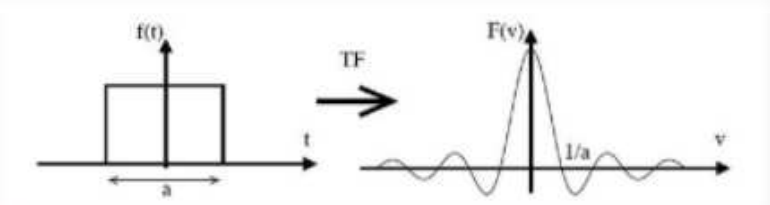


# Microwaves : définition et applications / telecom

Fourrier transform property : relation between time and frequency domain

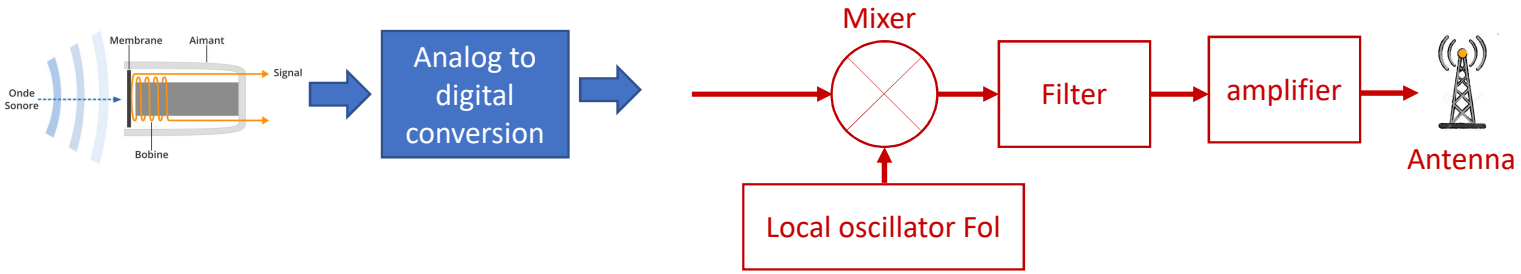



To conclude, to respect sampling constrains and to transmit a miximun number of signals in a same multiplex, it's interesting to lower a, then to increase the spectral width 1/a

Order of magnitude : voice signal, Fmax = 5 kHz, Fe=10 kHz, Te=0.1 ms, 4 bits encoding,
a = Te/4, F=40 kHz, 1 transmitted signal
a=Te/4000, F=40 MHz, 1000 transmitted signals

# Microwaves : definition and applications / telecom

Heterodyning technic : analog signal processing before the transmission/reception



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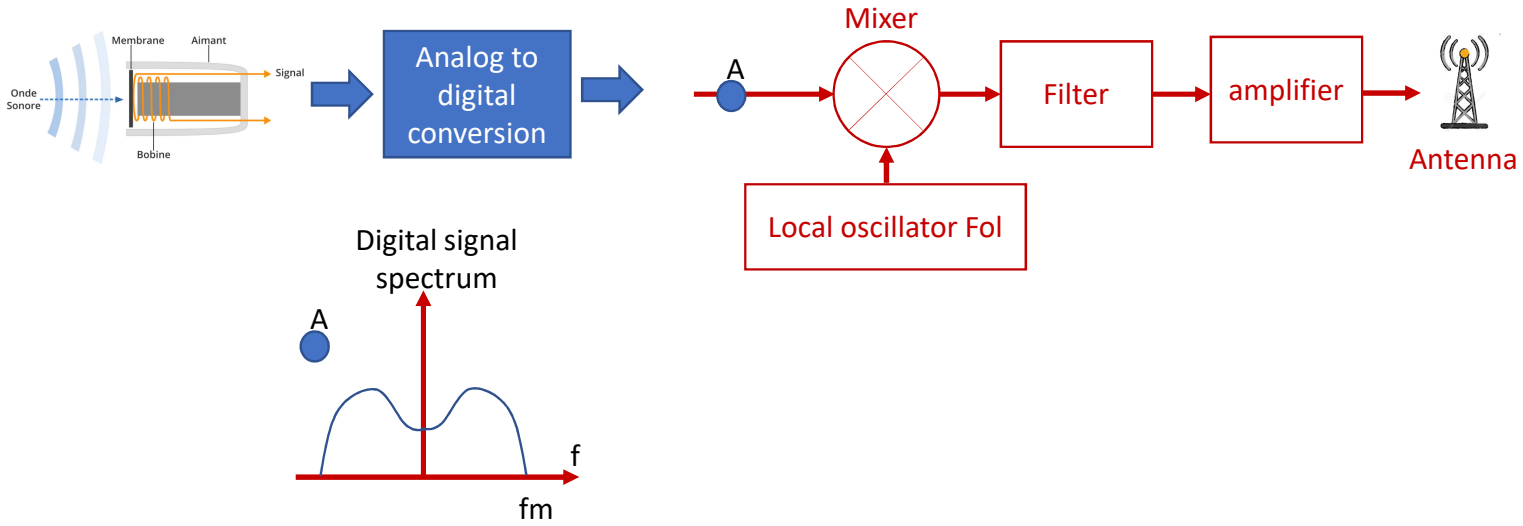

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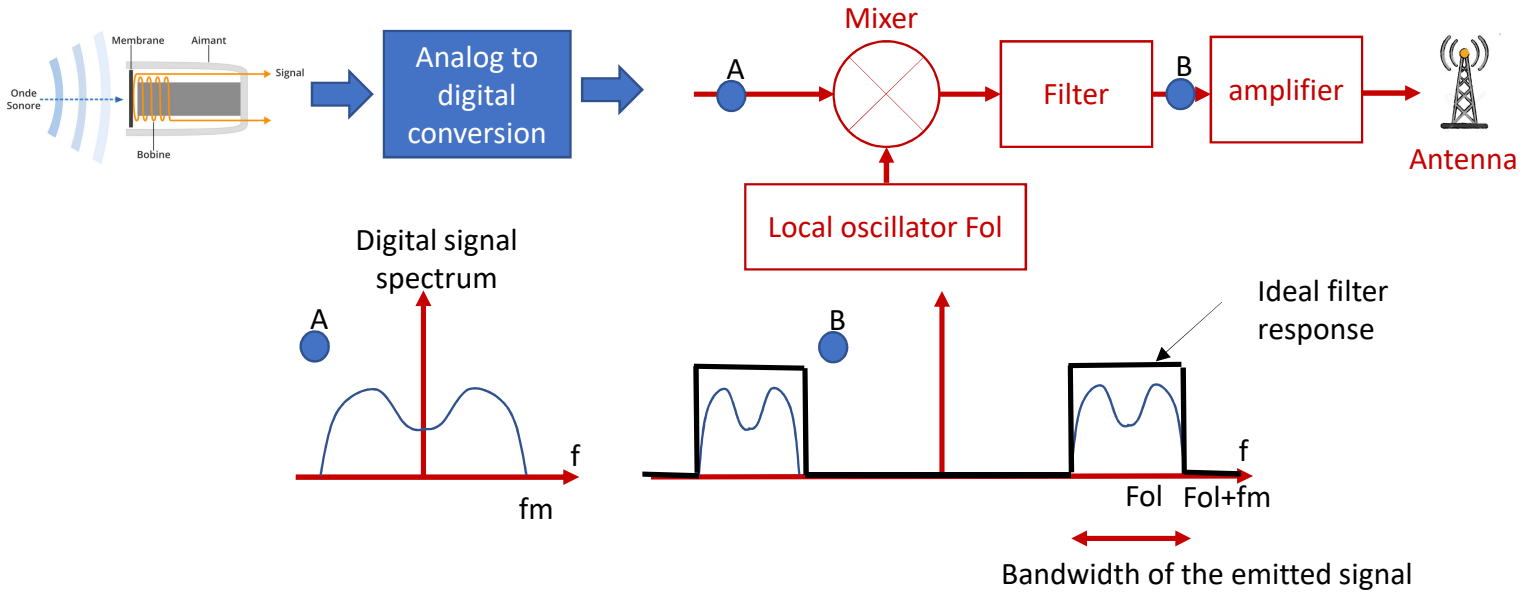
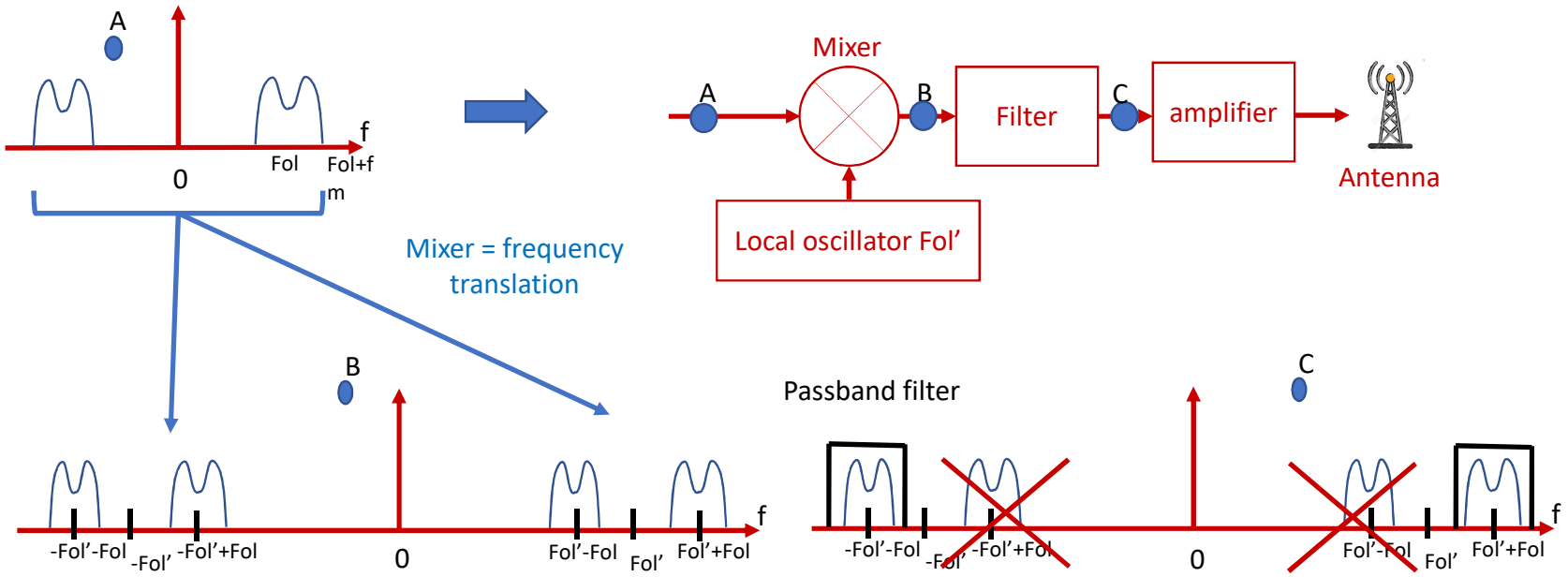


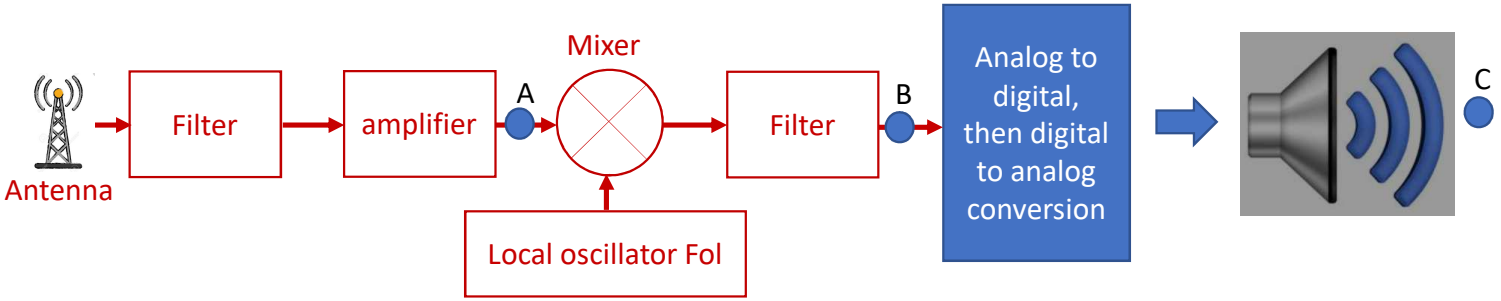
# Microwaves : definition and applications / telecom

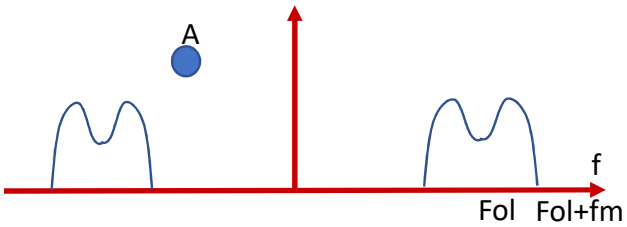
Complementary heterodynig technic : transmission of the baseband signal to an intermediate frequency

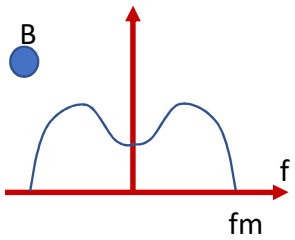


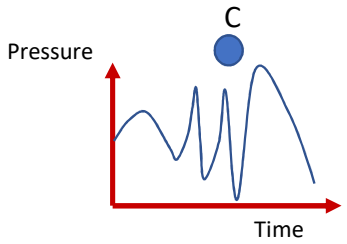
# Microwaves : definition and applications / telecom

Signal reception :



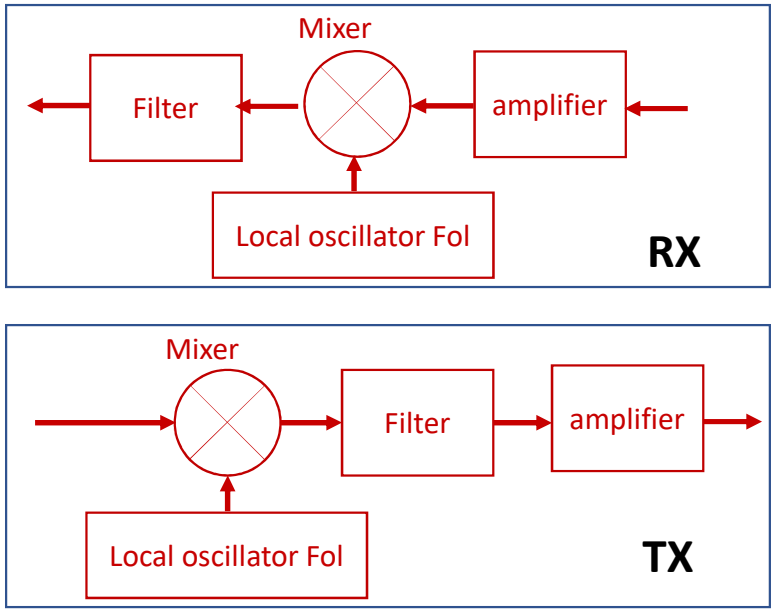



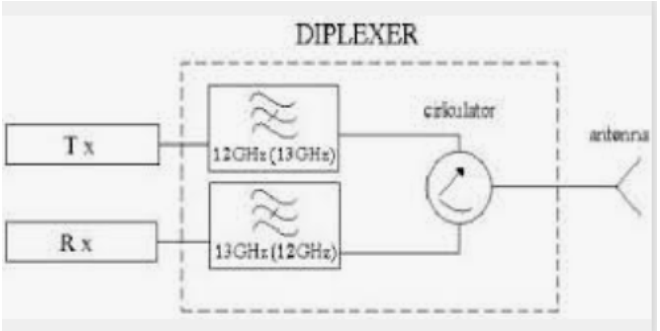



# Microwaves : definition and applications / telecom

'Transceiver', 'front end' : transmission and reception in a same circuit



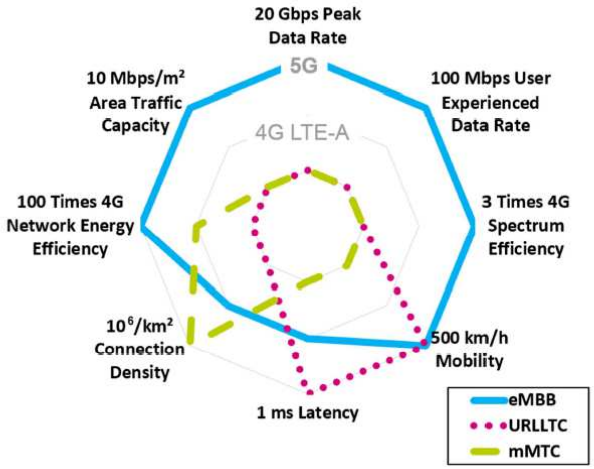




Technologies :

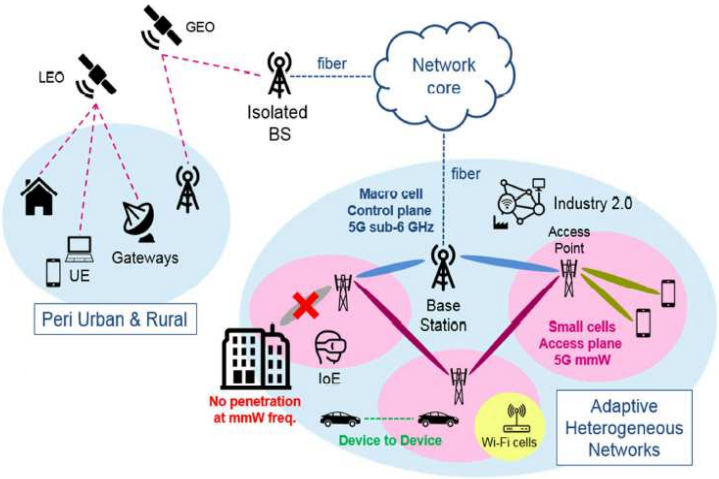
- Silicium reception functions réception (amplifier, mixer, LO)
- Si, GaN or emission functions
- Ferrite material in circulators
- Ceramic or organic material in filters, circuit and module packages, antennas

# Microwaves : definition and applications / telecom

5G : new services, new system architectures



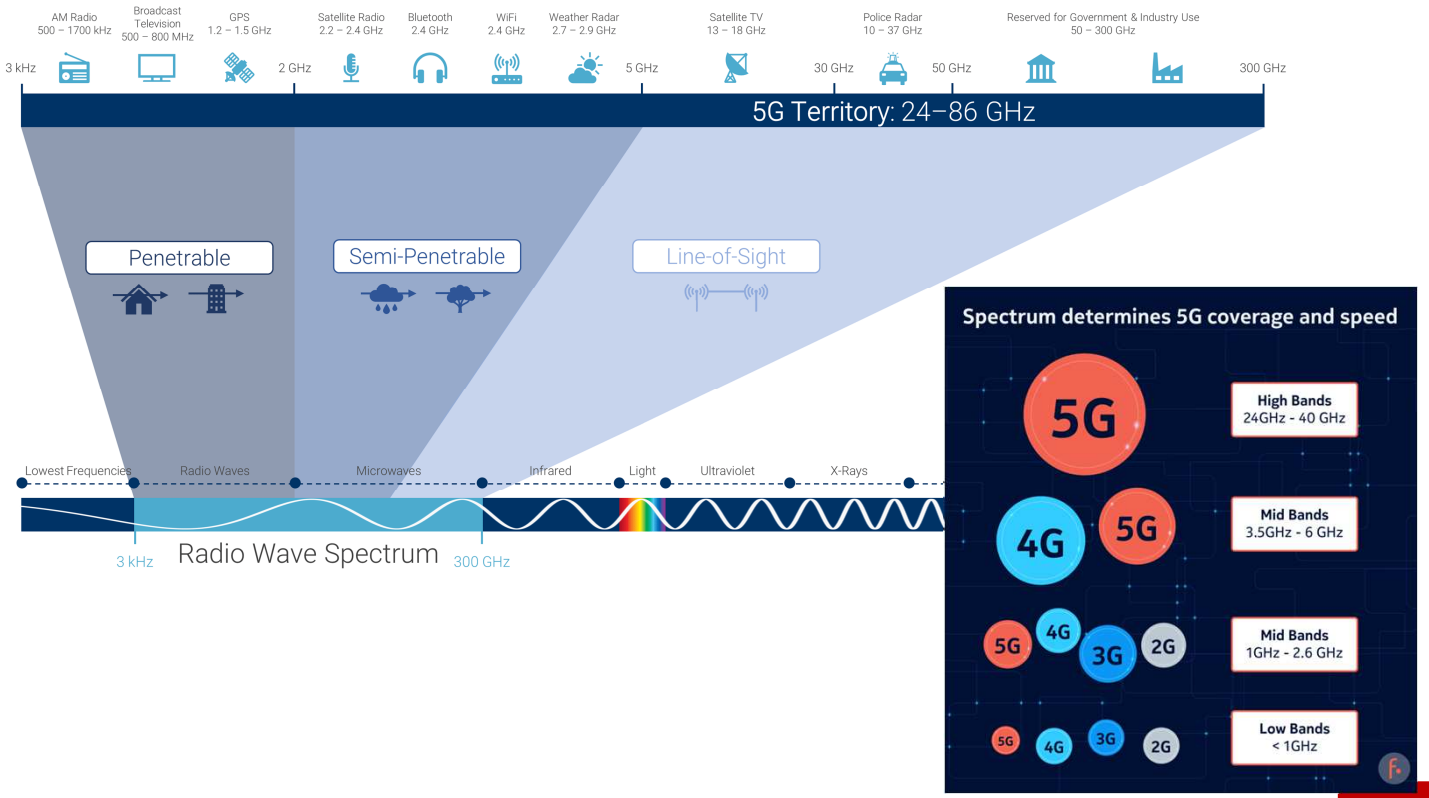

5G goals




Network organisation

# Microwaves : definition and applications / telecom

5G frequencies :

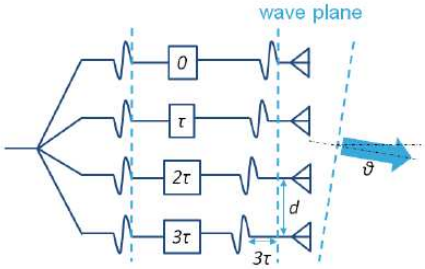


# Microwaves : definition and applications / telecom

5G : key technology, beamforming technic

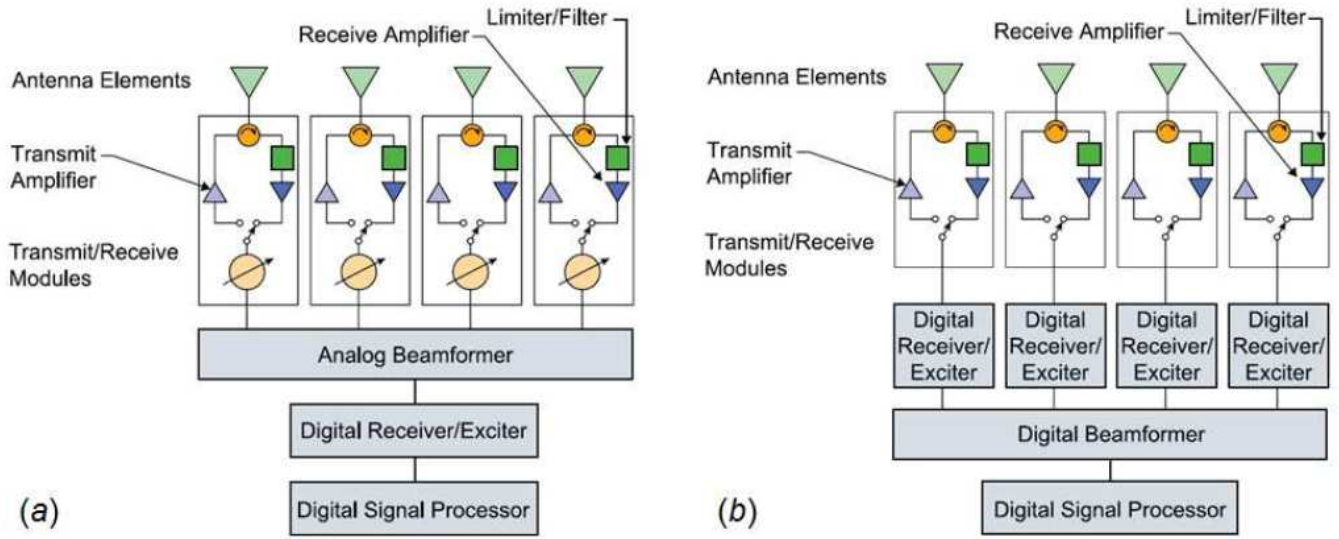

The technic used for focusing the wave :

- Several antennas (antenna network)
- The delays on each channel determine the emission/reception angle



# Microwaves : definition and applications / telecom

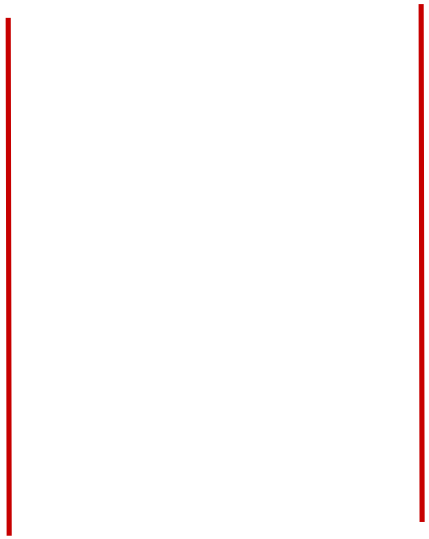
Technologies : digital signal proccessing, digital routing, but analog  antennas, amplifiers, filters, circulators, switches




*(a) Modern analog transceiver architecture; (b) Digital phased array transceiver architecture*

# Microwaves : definition and applications / antennas

- ✓ **Antennas : operating principal on a dipole**



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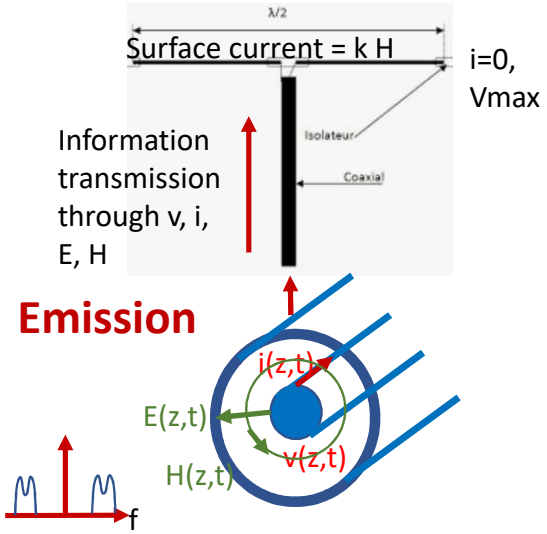

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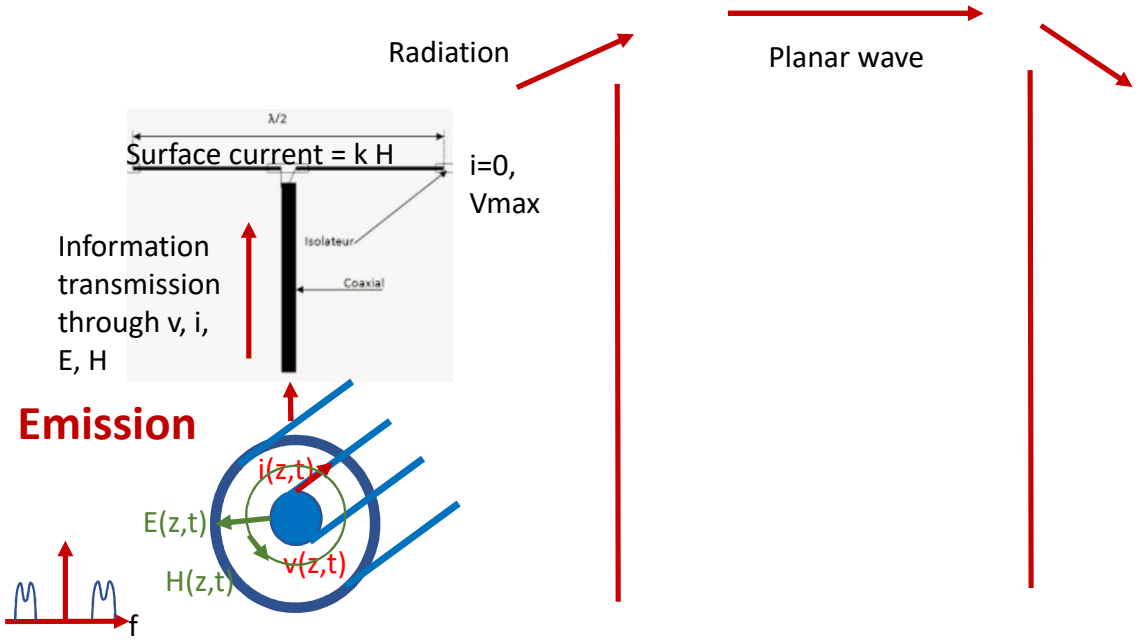

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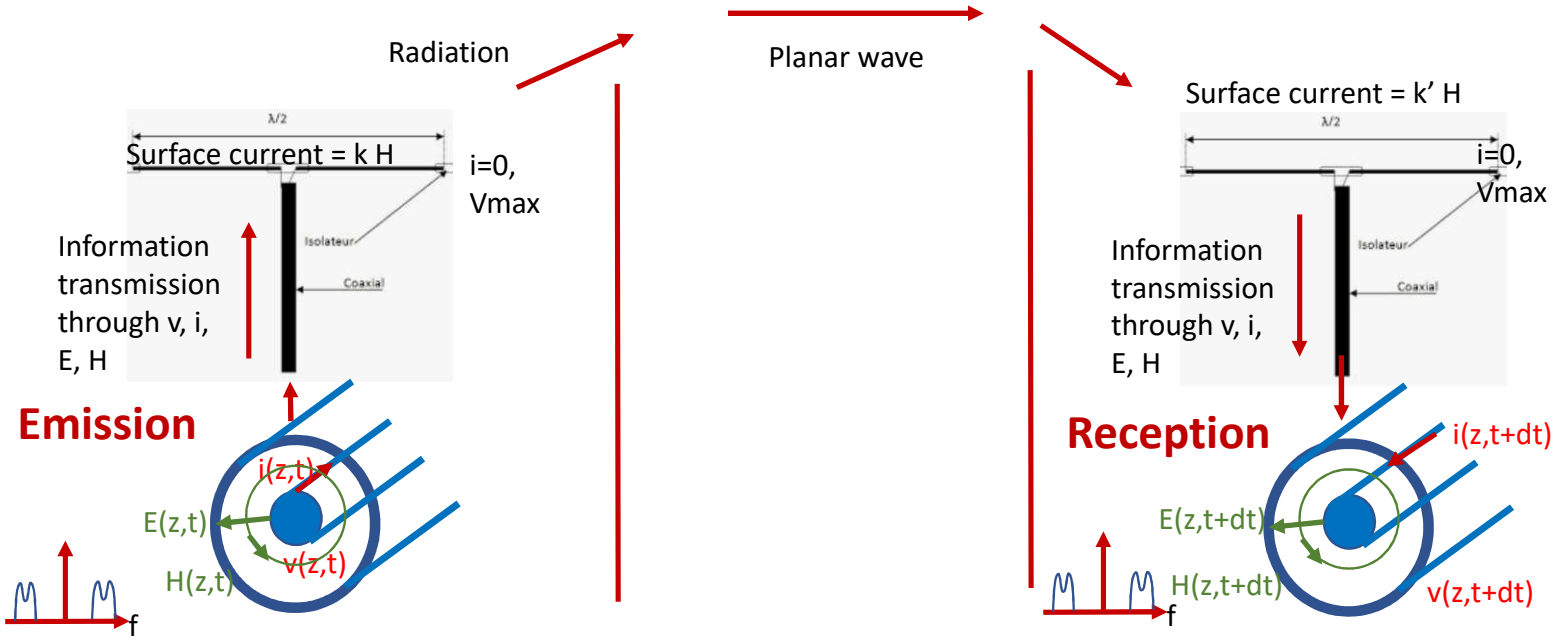
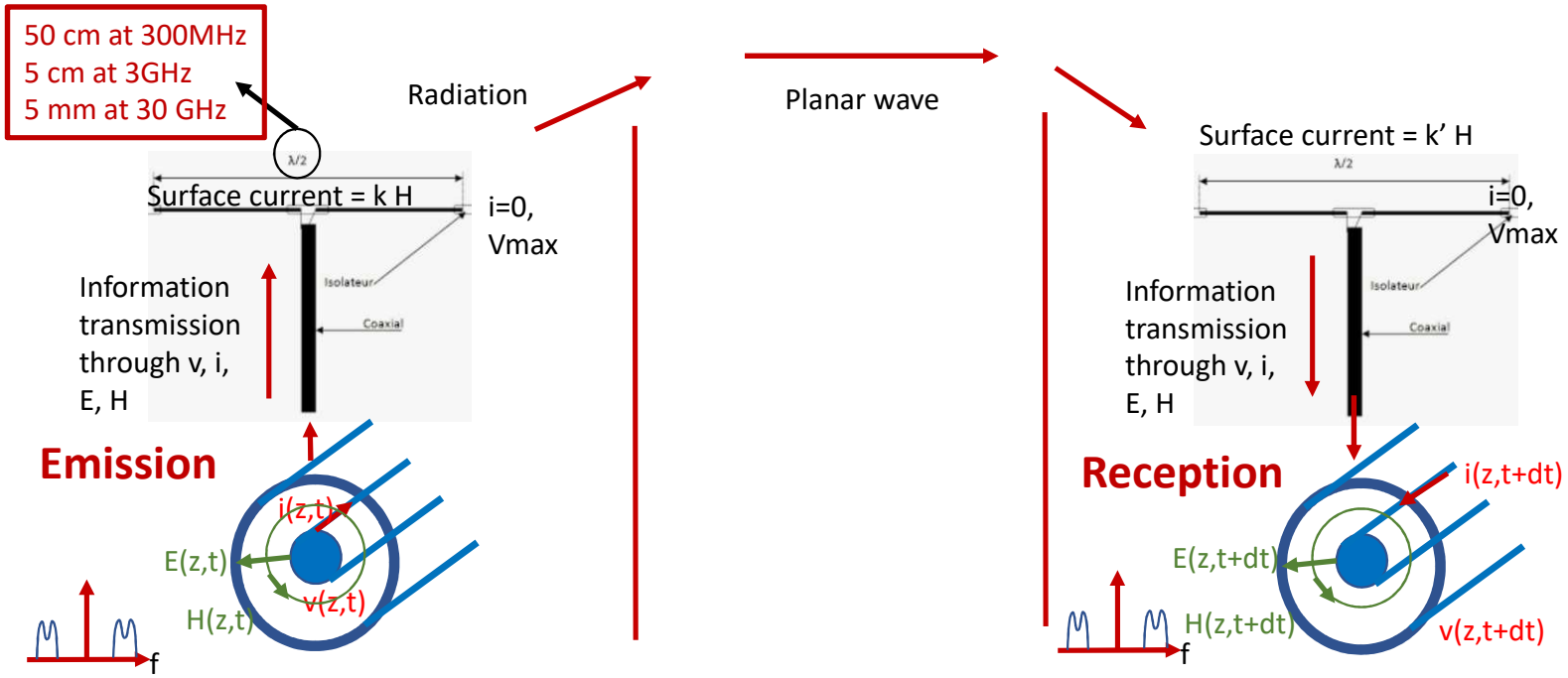


# Microwaves : definition and applications / antennas

✓ **Antennas : operating principal on a dipole**



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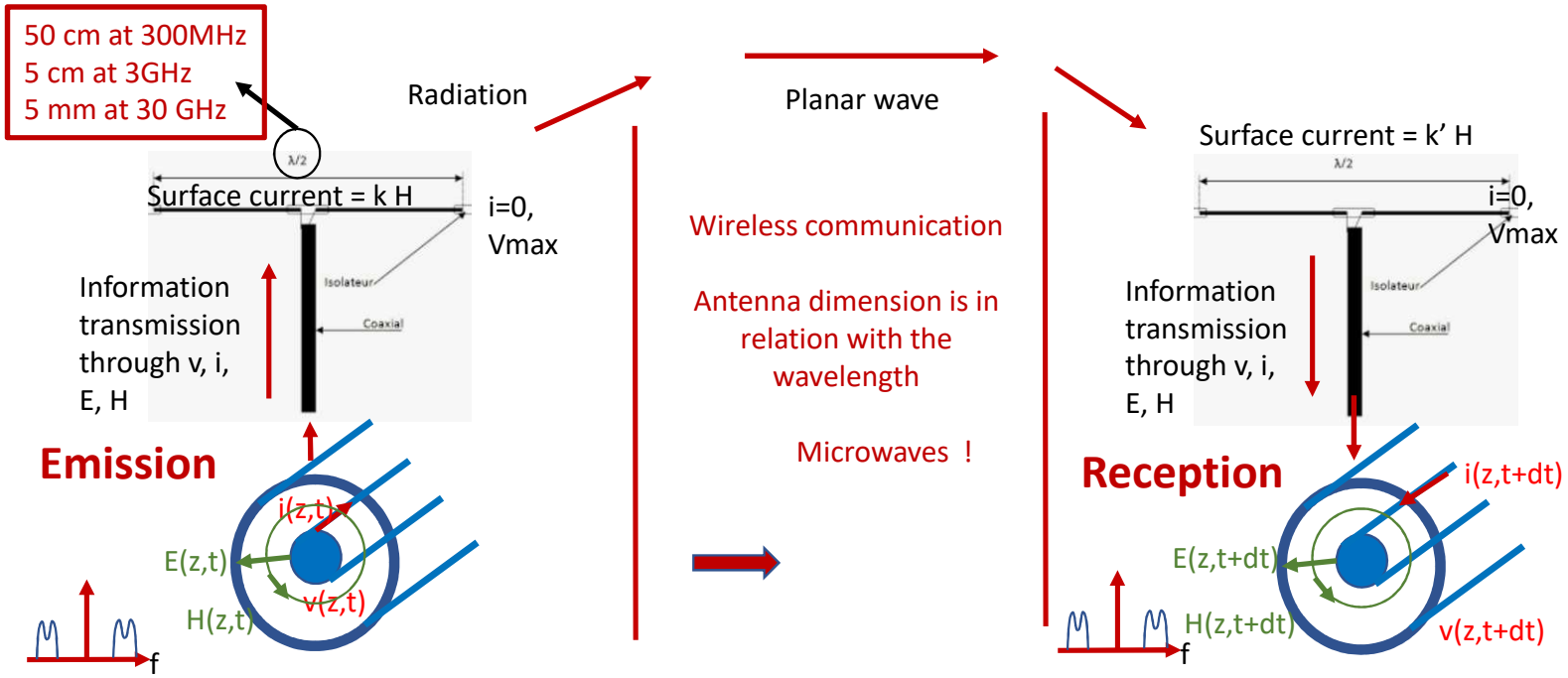
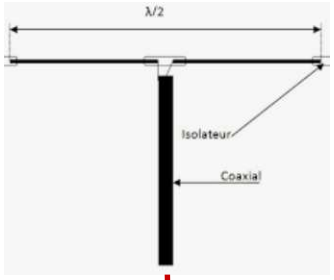
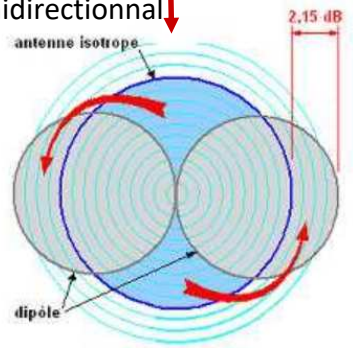


# Microwaves : definition and applications / antennas

## Pannel of antenna technologies

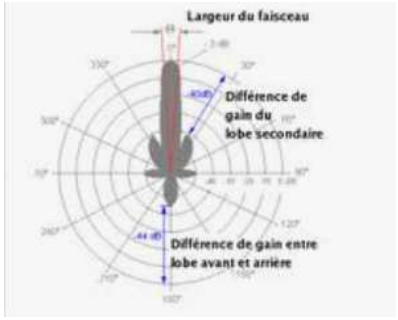



Omnidirectionnal

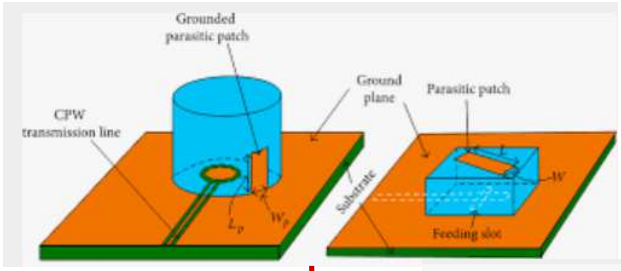



Parabolic antenna

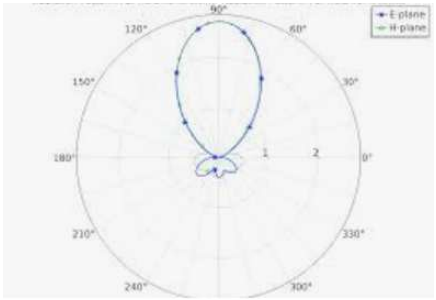
Focused

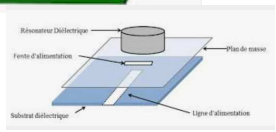



Dielectric resonator antenna (DRA)




Main lobe formation



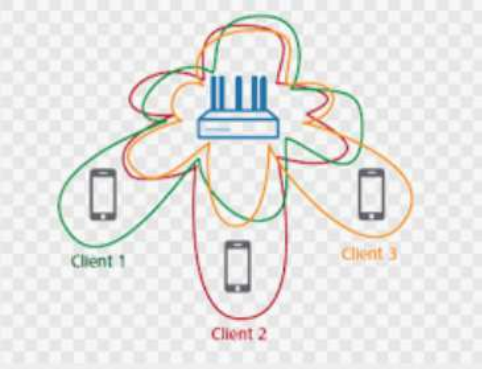



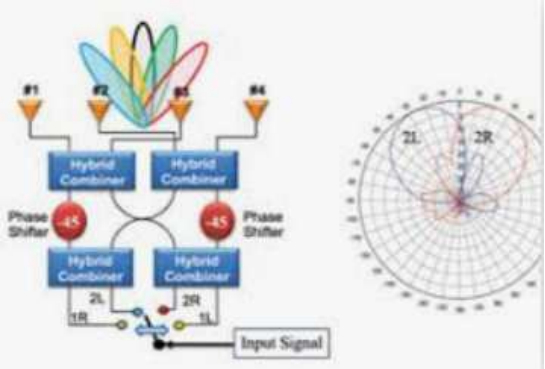
# Microwaves : definition and applications / antennas

## Antenna network: MIMO technic (multiple inputs multiple outputs)

Several antennas for the emission and for the reception. Different goals:

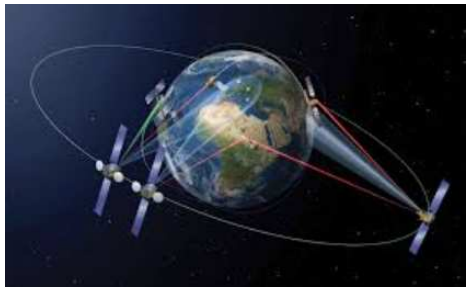
- Spatial diversity to receive several times the same signal, combining technics
- Multiplexing the signals on several pathes
- Beamforming technic to focuse different signals



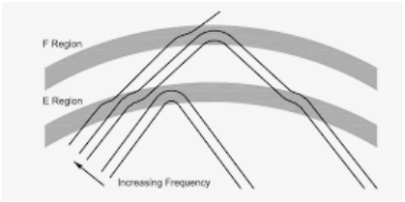
# Microwaves : definition and applications / Satellites

## Spatial transmission

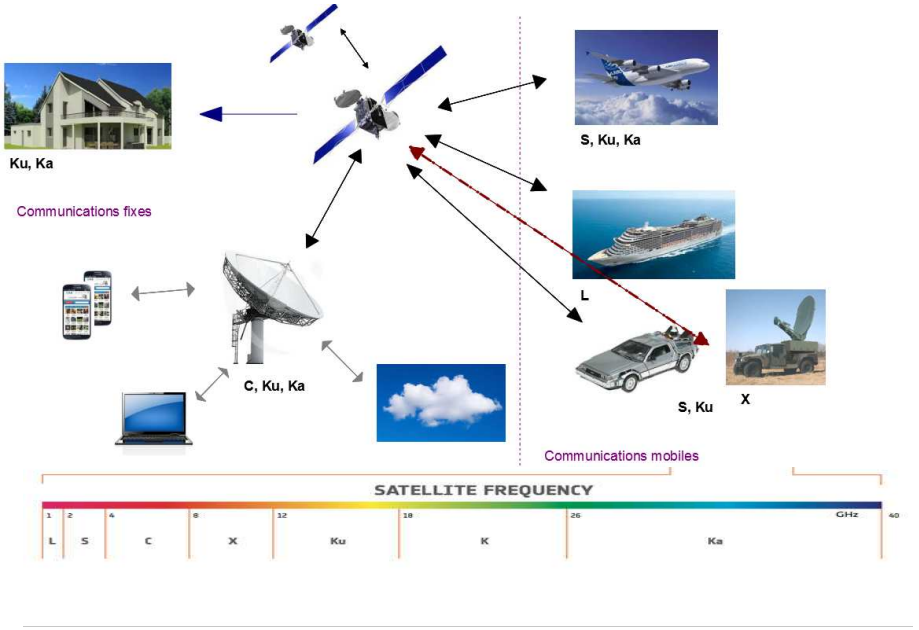


Communication on very long distances, but it's necessary to cross the atmospheric layers(ionosphere)

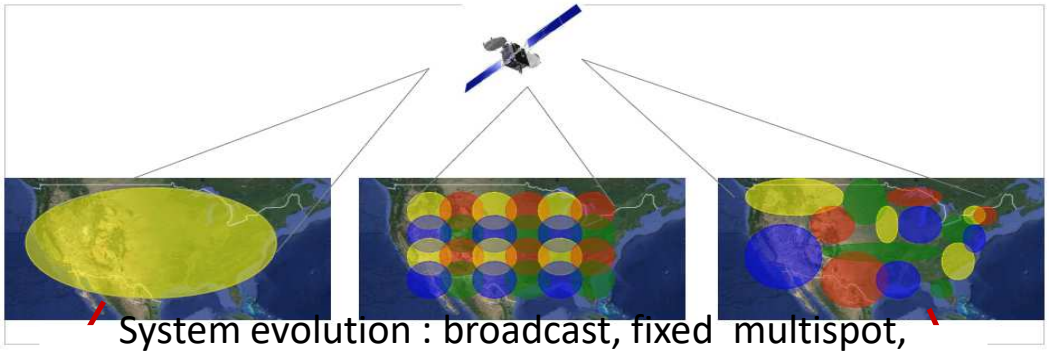
➡ Microwaves (for data rate too)!



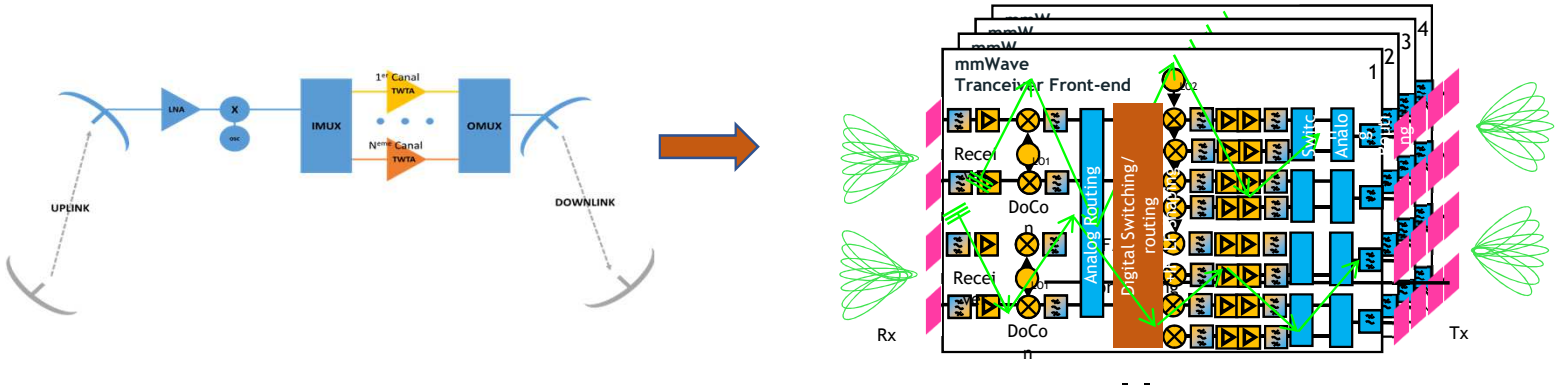

Frequency band used:



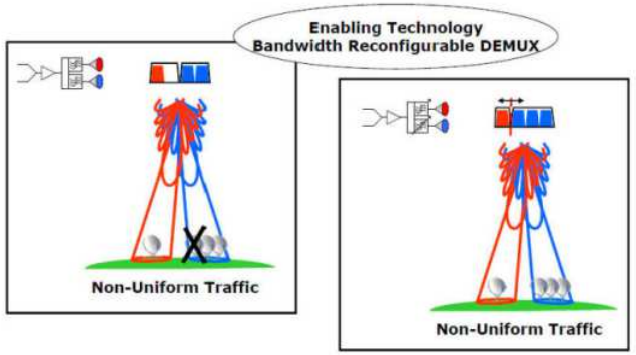
# Microwaves : definition and applications / Satellites



System evolution : broadcast, fixed multispot, Adaptative multispot



# Microwaves : definition and applications / Satellites

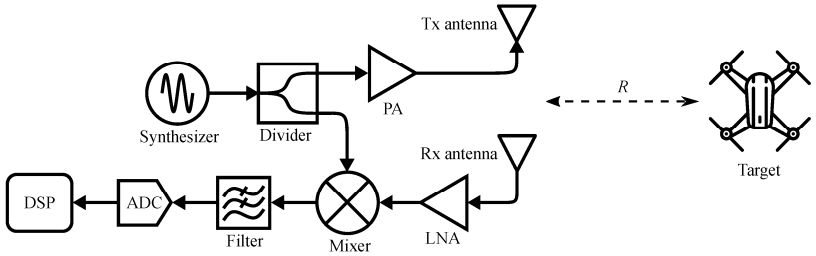


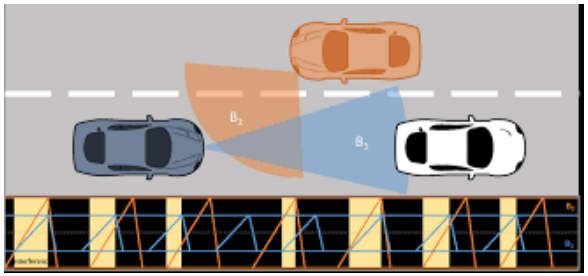

Low earth orbit :

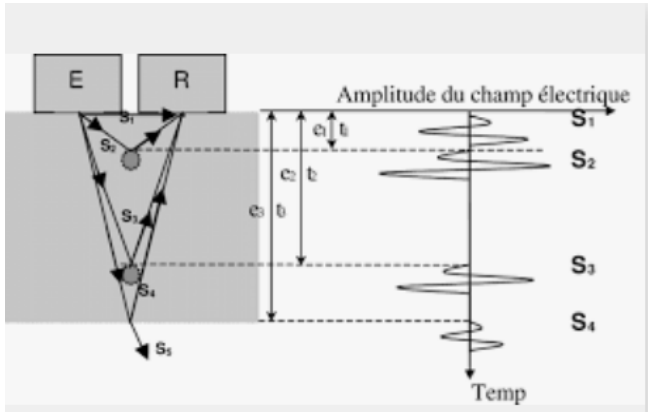
- A capability to match the network to the customer requirements
- Cost reduction for each satellite
- A higher number of satellites
- Less required signal power, lower signal latency


Facebook drones, Google balloon fro internet communications

# Microwaves : definition and applications / Radars






Pulse width ↘ ➡ Resolution ↗

➡ Bandwidth ↗

**Microwaves !**

Similar components in radar systems than in telecom ones

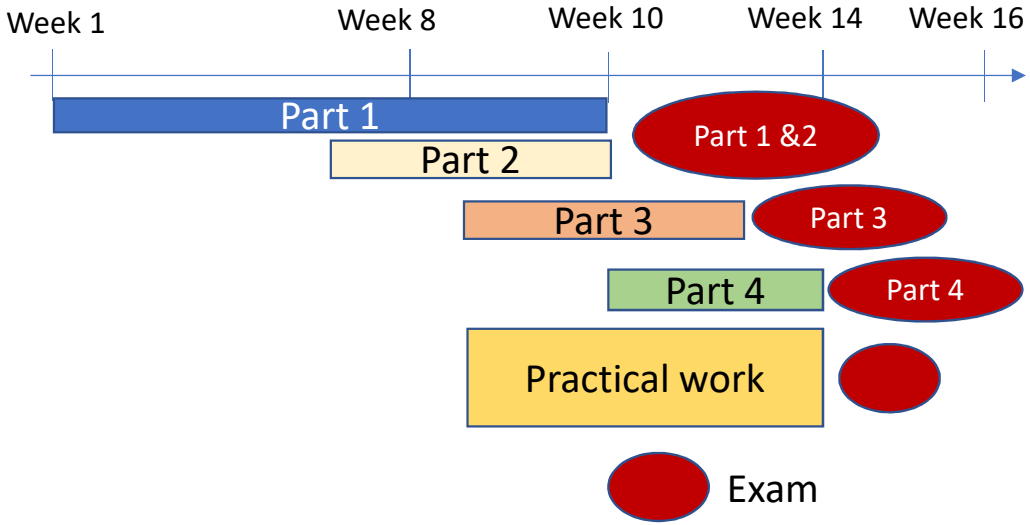
# Course outline

**Part I - (S. Verdeyme (SV), 24h)**
- Maxwell Equations in waveguides
- EM fields, current, voltage in transmission lines
- Transmission line theory (transient and steady states)
- EM Fields in metallic rectangular

**Part II - (O. Tantot (OT), 15h)**
- S parameters (N-ports microwave networks)
- Smith chart

**Part III - (O. Tantot (OT), 9h)**
- Antennas
- Antennas array

**Partie IV - (P. Blondy (PB), 17h)**
- Lumped components – Si technologies
- Matching networks




**Mark computation :**

**Part1+part2 : coef 0.45**
**Part 3 : coef 0.1**
**Part 4 : coef 0.2**
**Practical work : coef 0.25**

# Course outline

**Practical Works (C. Dalmay, A. Périgaud, 24h)**

- CAD with Momentum (Advanced Design System)
  - Microstrip elements : stub, half wavelength resonator, 2nd order filter
  - Multilayer microstrip inductance

- CAD with HFSS (Ansys Electromagnetics)
  - Microstrip and coplanar lines and striplines, coupled lines
  - Rectangular and circular waveguides and different loading elements
  - Parallelepipedal and cylindrical cavity (eigenmodes, selective excitations and coupled cavities)
  - Directional and hybrid couplers

# Skills

**At the end of this semester, you will be able to :**

- **interpret how a microwave signal propagates between micowave components and circuits. Expert level**
- **use specific microwave tools, to characterize the function of a microwave component. Expert level**
- **design microwave components R, L, C. Intermediate**
- **design the passive part of a complex circuit. Beginner**

# SV course organisation

**Duration :** 24 h, 16 slots (8 lesson sessions, 8 tutorial ones), from september to november

**Training method** : Lessons written on white-board or graphic tablet (moodle platform). You have to take down what I write and say, the best way to understand and memorize.
I will ask you a number of questions during the lesson : try to answer, and feel free to ask questions

Exercices given during the lessons (extra to tutorials). Do them yourself or in small groups. Appointments to fixe together if you have problems to find the solution