Introduction

Course information

- Ex-cathedra courses:
  - 19.02
  - 04.03 (by zoom)
  - 11.03
  - 25.03
  - 15.04
  - 22.04
  - 29.04
- Student presentations
  - 06.05, 13,05, 27,05
- Labs:
  - TBD (4 sessions)

Evaluation

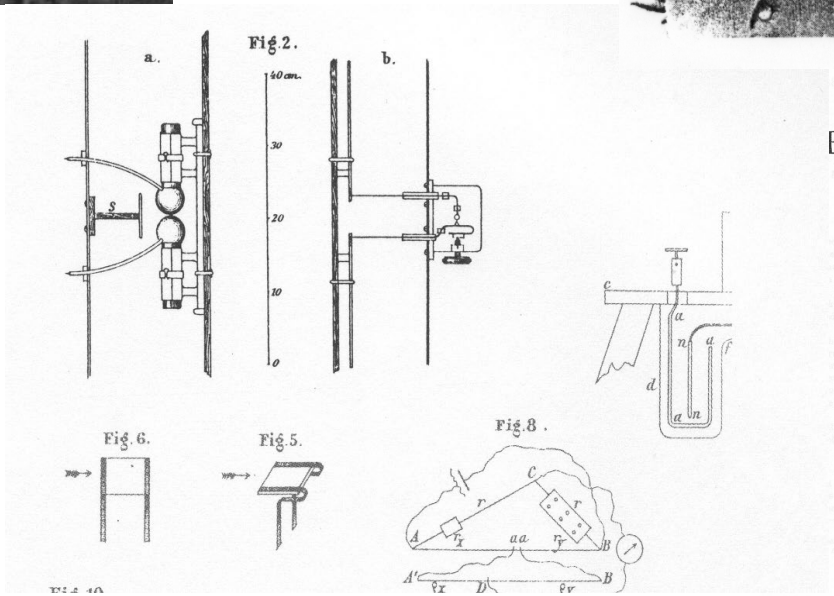
- Each student will present a topic related to microwave or microwave measurements
- The grade will depend on this presentation, the according slides and participation in the labs

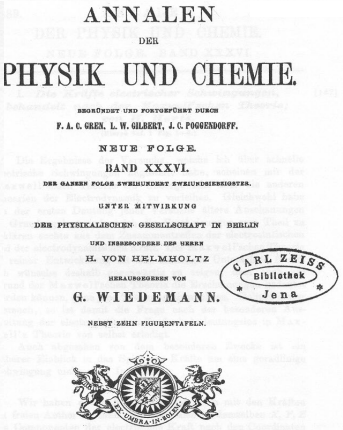
History

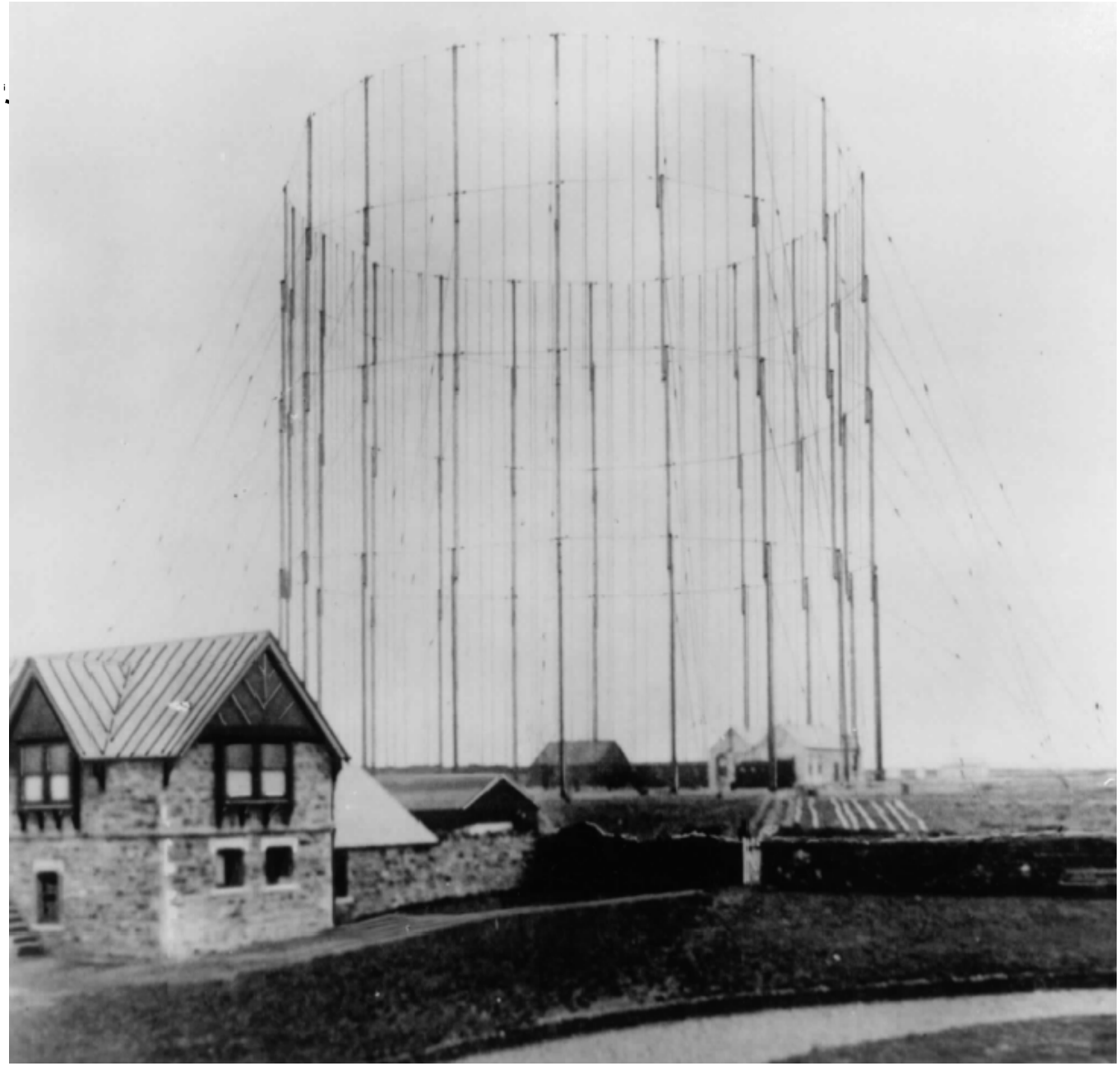
1872	Publication of "a treatise on electricity and magnetism" by James Clerk Maxwell
1887	Publication of Oliver Heaviside's comments on Maxwell's work
1887	Lord Rayleigh proves theoretically the concept of waveguides
1891	Experimental verification of Maxwell's theory by Heinrich Herz (experiment at 1 GHz)
1901	First transatlantic wireless link by Guglielmo Marconi
1903	Regular wireless telegraphic service
1918	First tubes and continuous wave generators
1920	First use of frequency shifters in detectors, mixers, and receivers
1938	First Portable phone (Motorola)

From Maxwell (1865) to Hertz (1888)

Heinrich Hertz (1857–1894). (Photograph courtesy of Deutsches Museum, Munich.)

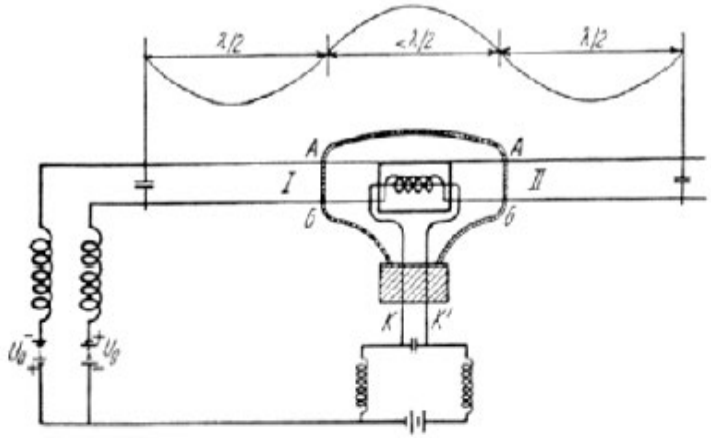


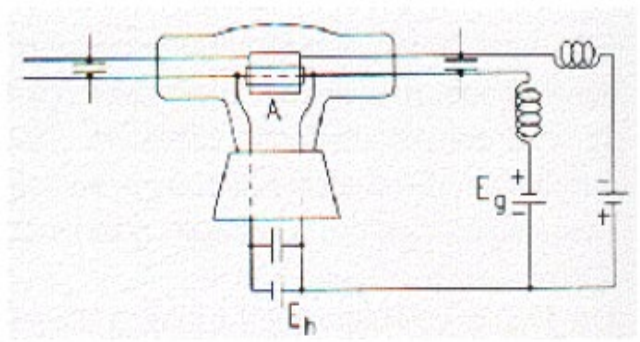


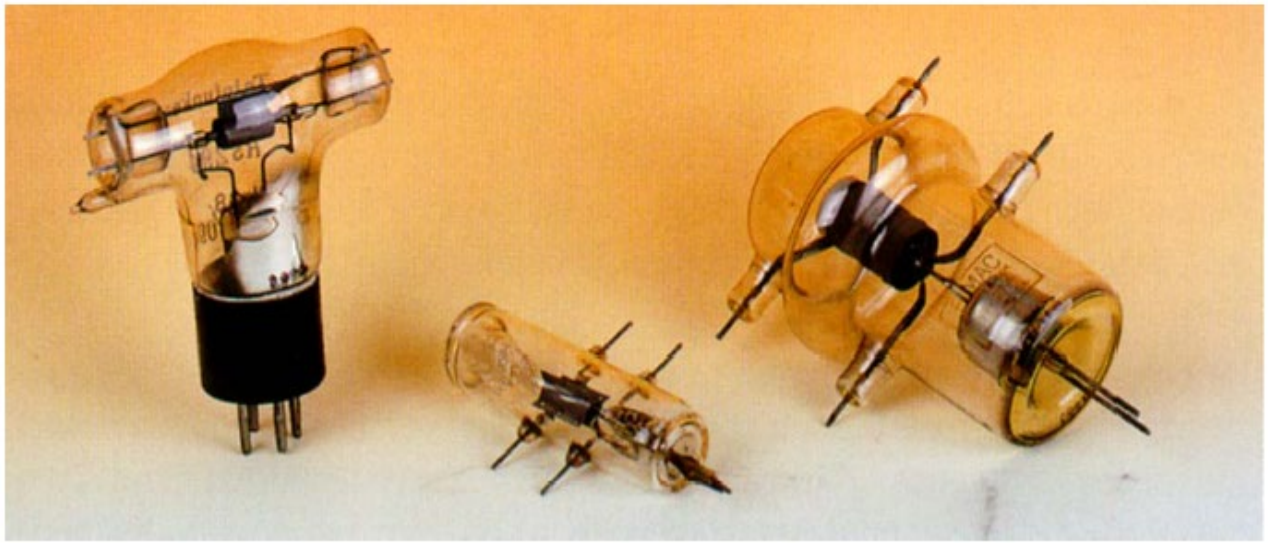


Photograph of the original conical antenna system installed at Poldhu, Cornwall (after **BAE Systems Marconi Research Centre, Chelmsford, Essex**)

Microwave tubes







Retarding-field tube RS296 and its circuit (Kühle 1932 at Telefunken)

"Hammer Tube" [8,11]. The photograph also shows the retarding field tubes 8012 of RCA (middle) and VT 127 A of Eimac (right)

History

1936 Simultaneous rediscovery of the waveguide concept by G.C. Southworth and W.L. Barrow

1938-1945 : intensive research on RADAR

1948 Distributed filter theory by Richards

1950 First cavity filters

1950 Introduction of planar microwave transmission lines (first stripline, then microstrip)

1950 Apparition of TWT amplifiers

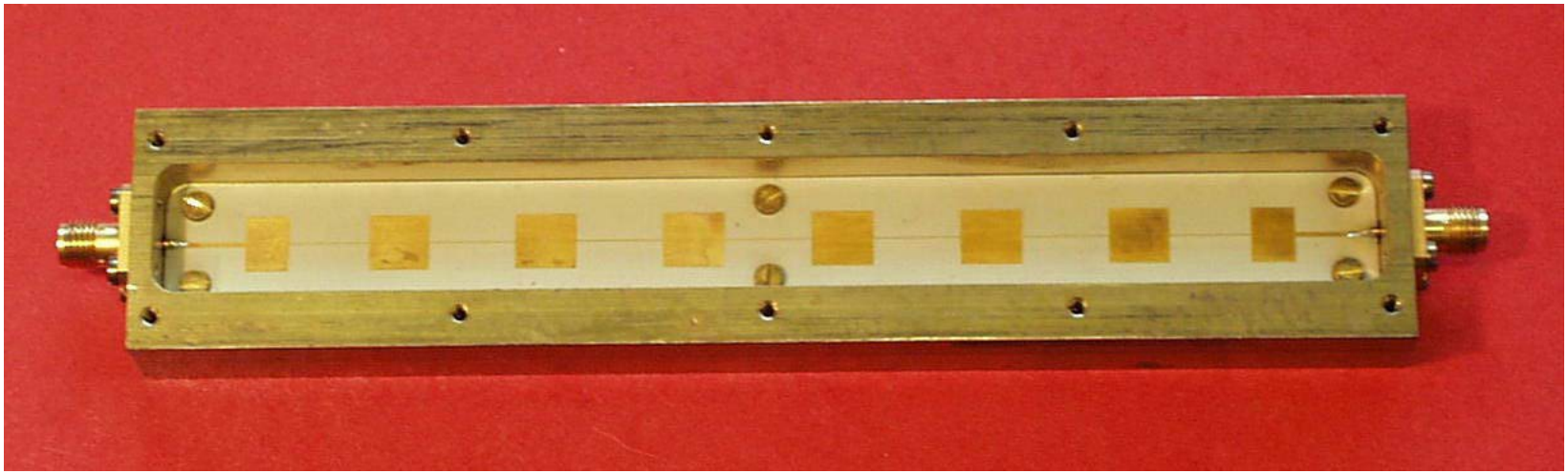
1960 Apparition of the first microwave transistors

1970 First MMICs

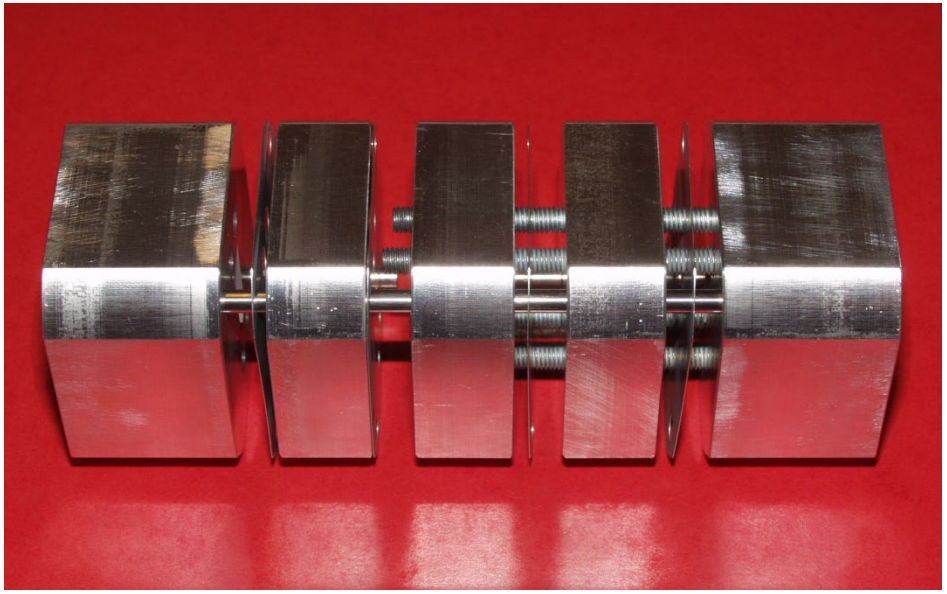
1971 First CAD tools

1990 Start of wireless communication boom

example of distributed filter:
LPF realized in microstrip technology

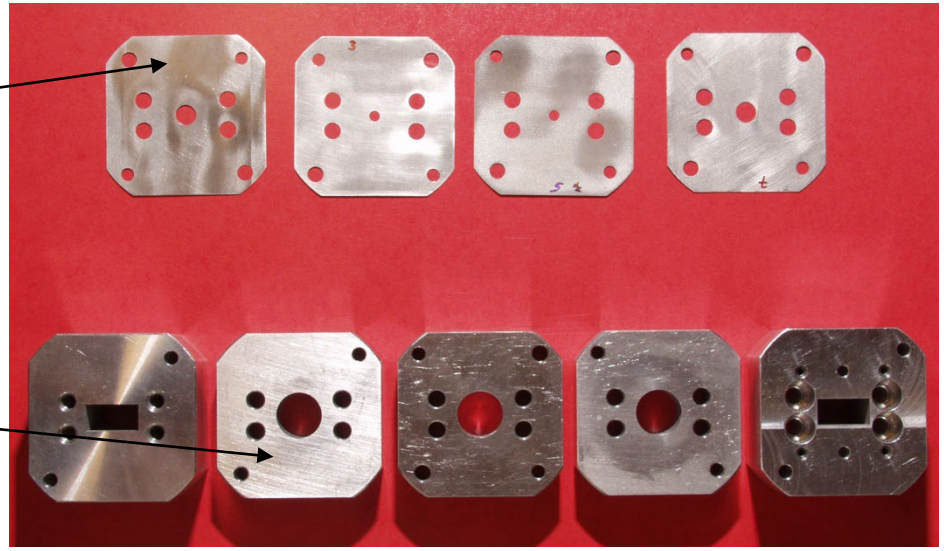


cavity filter
(exploded)

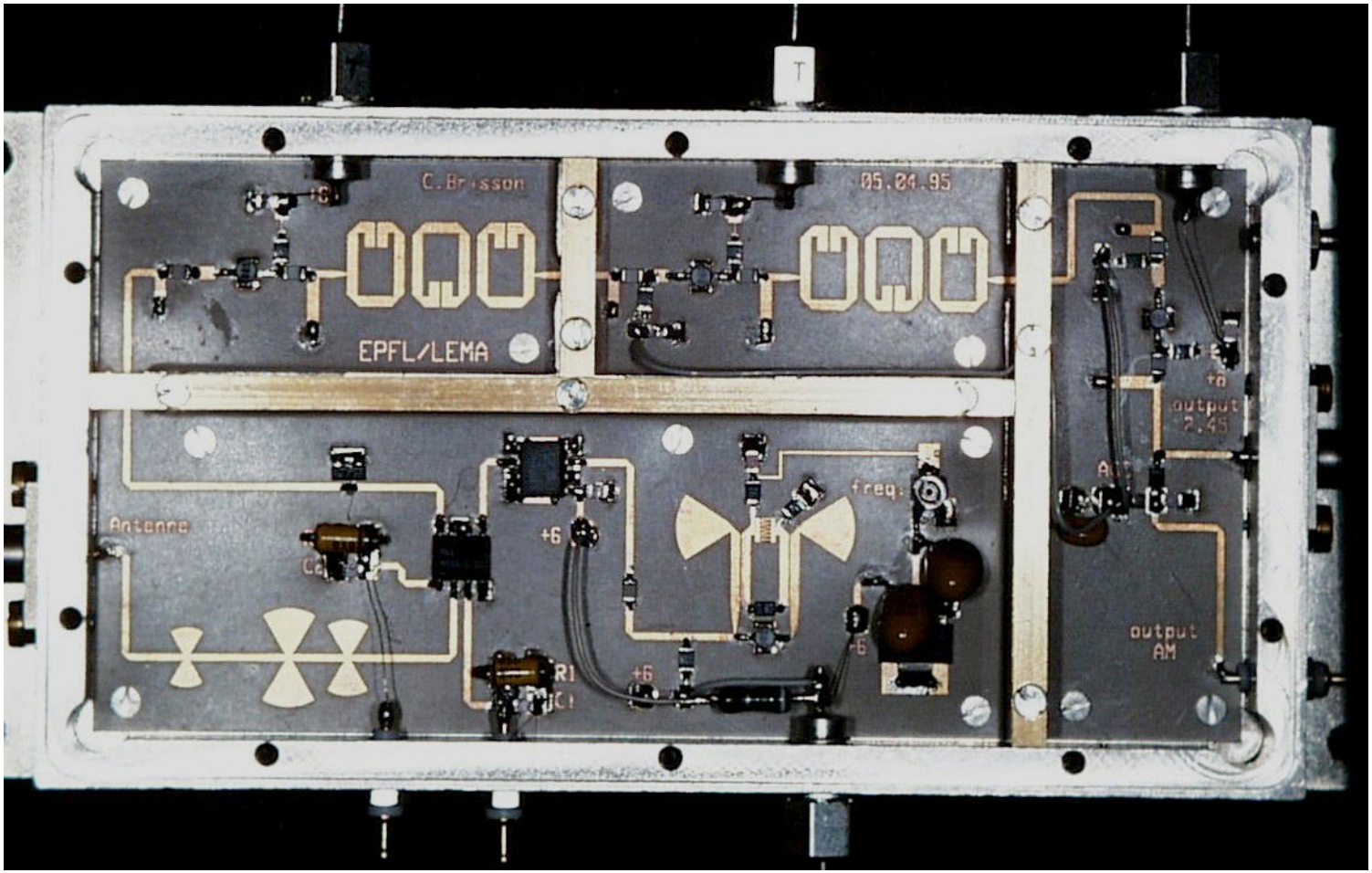


irises

waveguide sections

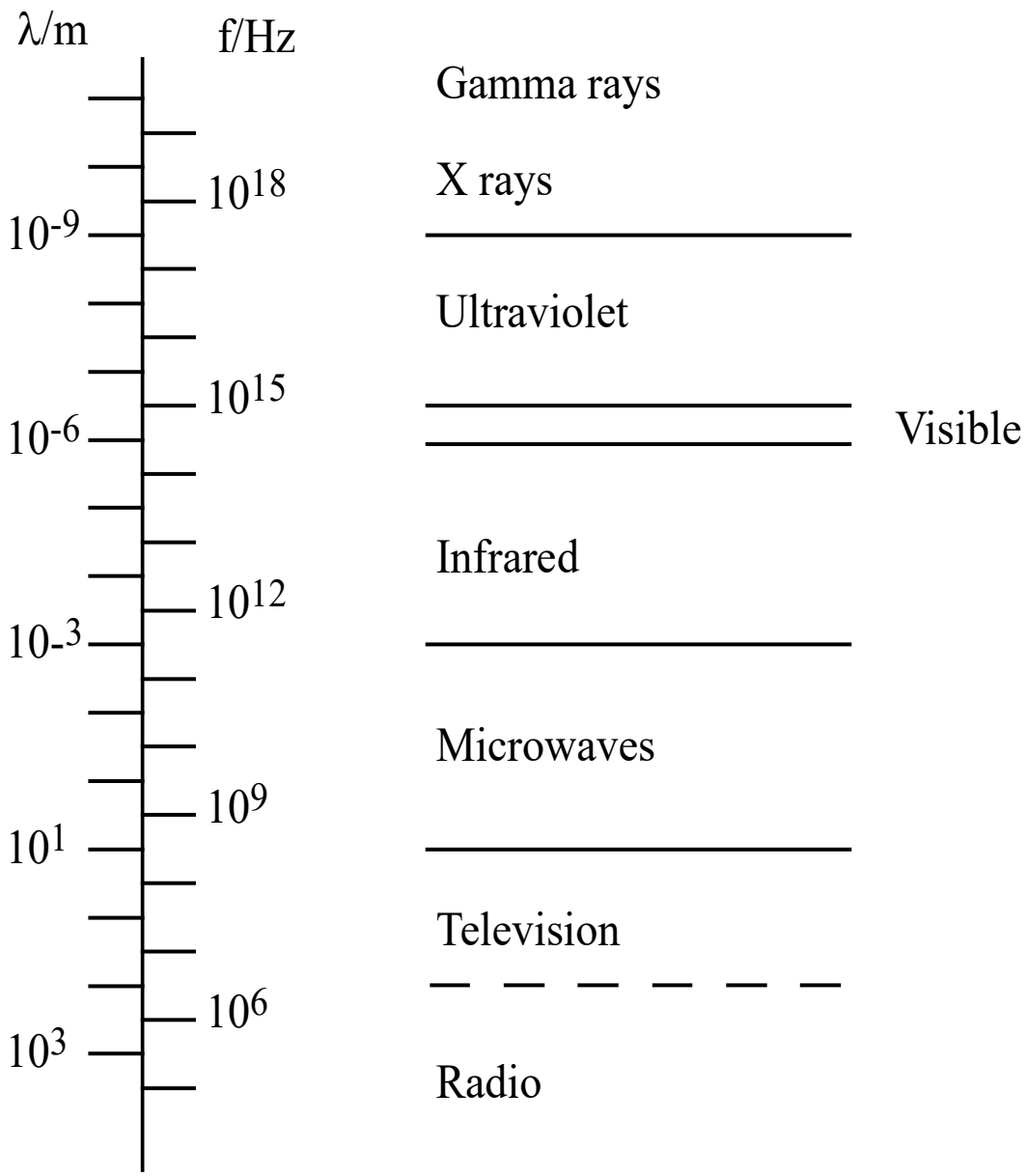


example of microstrip circuit: complete 2.45 GHz transceiver



Definitions of microwaves

Frequency (f)	300 MHz-300 GHz
Period (T)	3 ns - 3 ps
Wavelength (λ)	1 m - 1 mm
Energy (hf)	1.2 10^{-6}eV - 1.2 10^{-3}eV


λ/m
f/Hz
Gamma rays
X rays
Ultraviolet
Visible
Infrared
Microwaves
Television
Radio
10^18
10^15
10^12
10^9
10^6
10^3
10^1
10^-3
10^-6
10^-9

Band	Frequency
L	1-2 GHz
S	2-4 GHz
C	4-8 GHz
X	8-12 GHz
Ku	12-18 GHz
K	18-26 GHz
Ka	26-40 GHz
Q	40-60 GHz
E	60-90 GHz

Properties of microwaves

- Bandwidth
  - 1% of 10 GHz = 100 MHz, but 1% of 100 MHz = 1MHz
- Transparency of the Ionosphere
  - Satellites

Properties of microwaves

- Transparency of the atmosphere up to 10 GHz
- Electromagnetic noise Minimum between 1 and 10 GHz, + low noise amps

Atmosphere

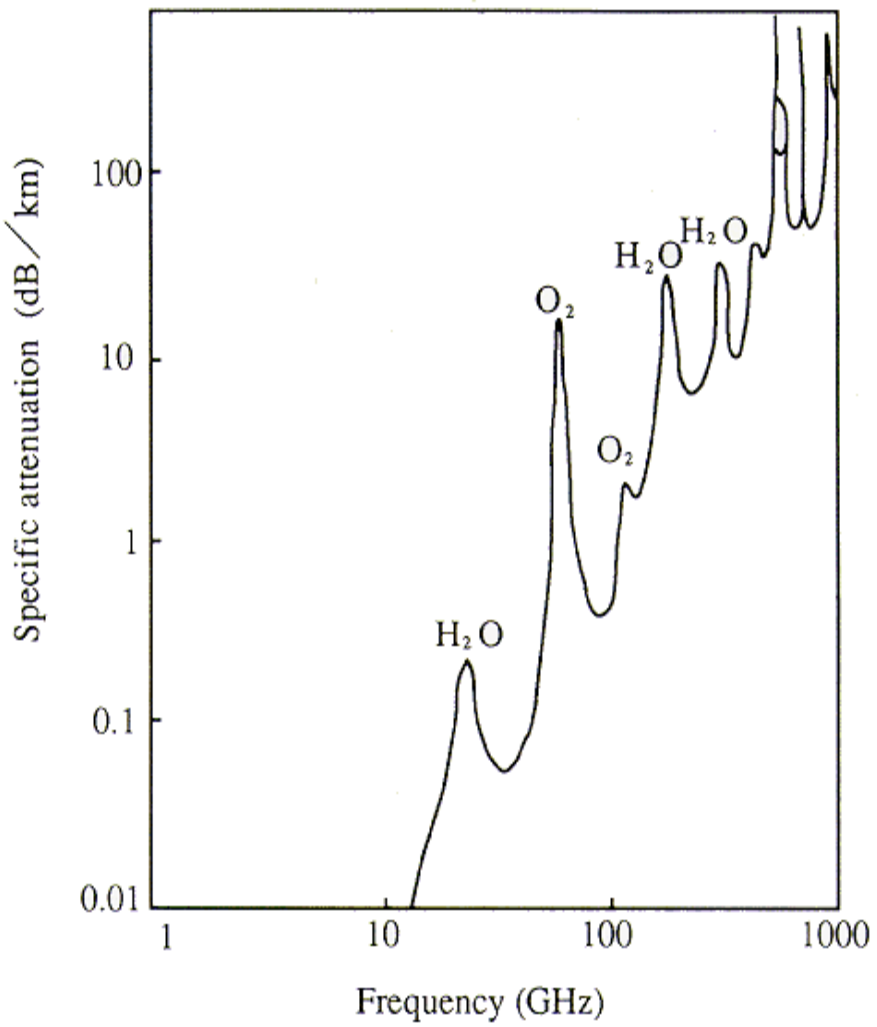
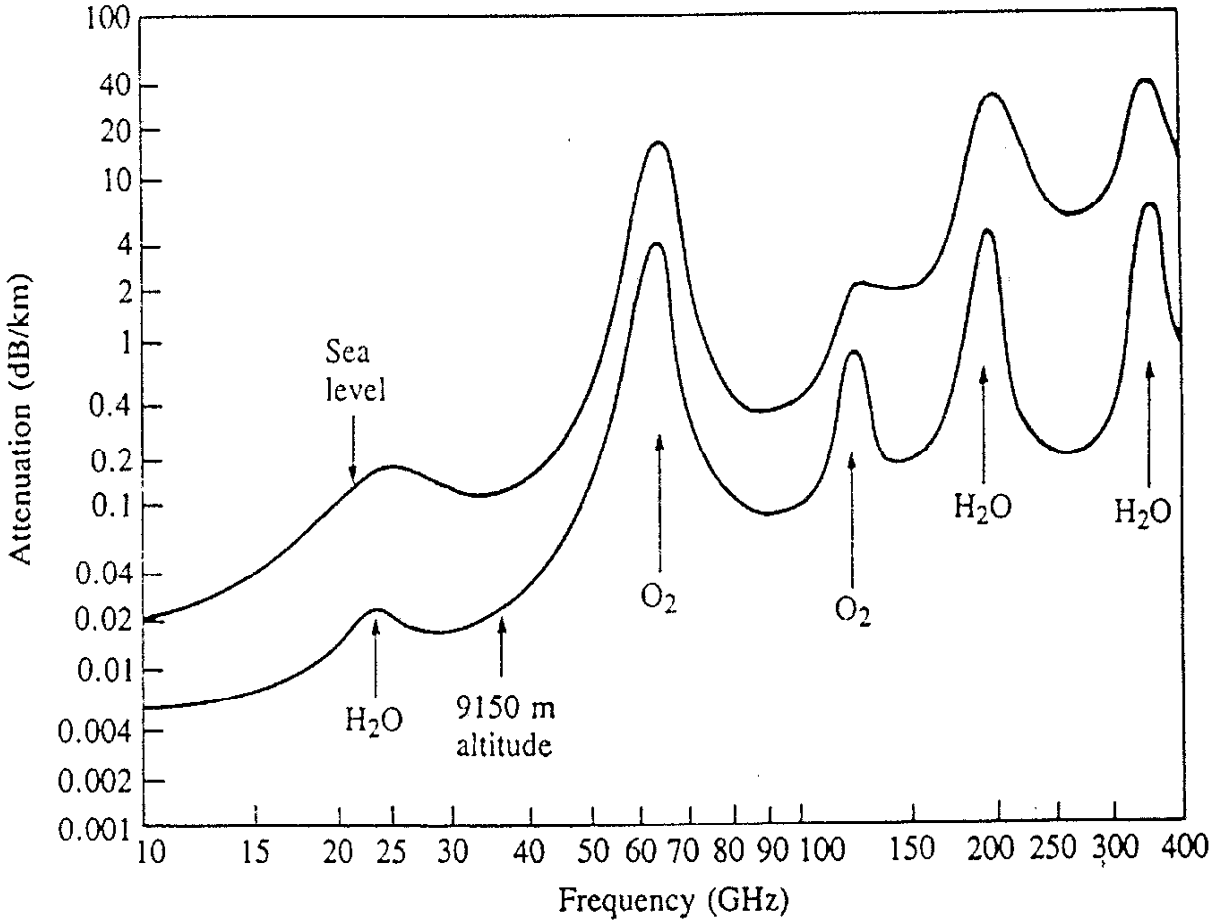


Fig.3.2.1 Microwave absorption due to atmospheric gases

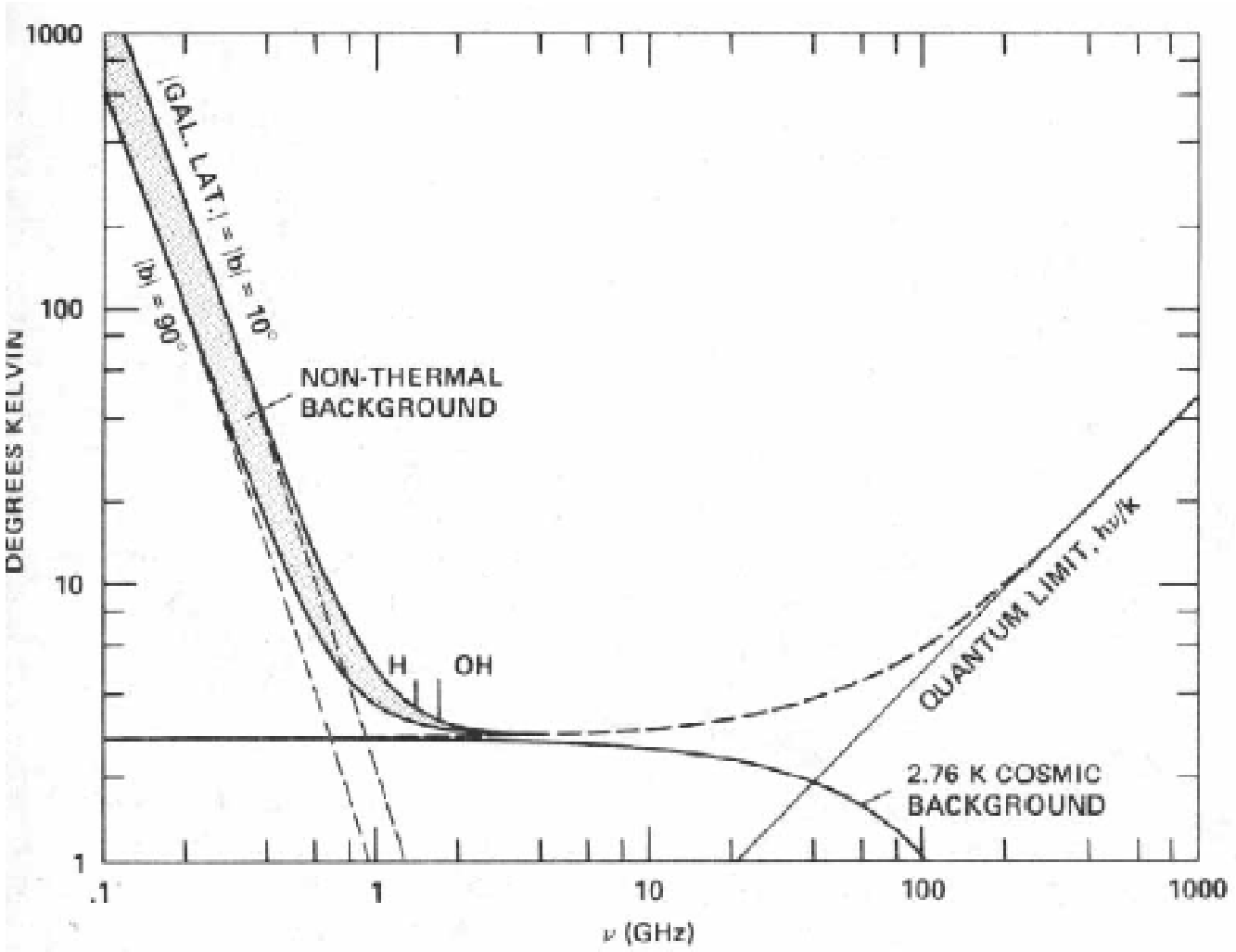
strategic use of the atmospheric absorption!

detection of pollution from satellites

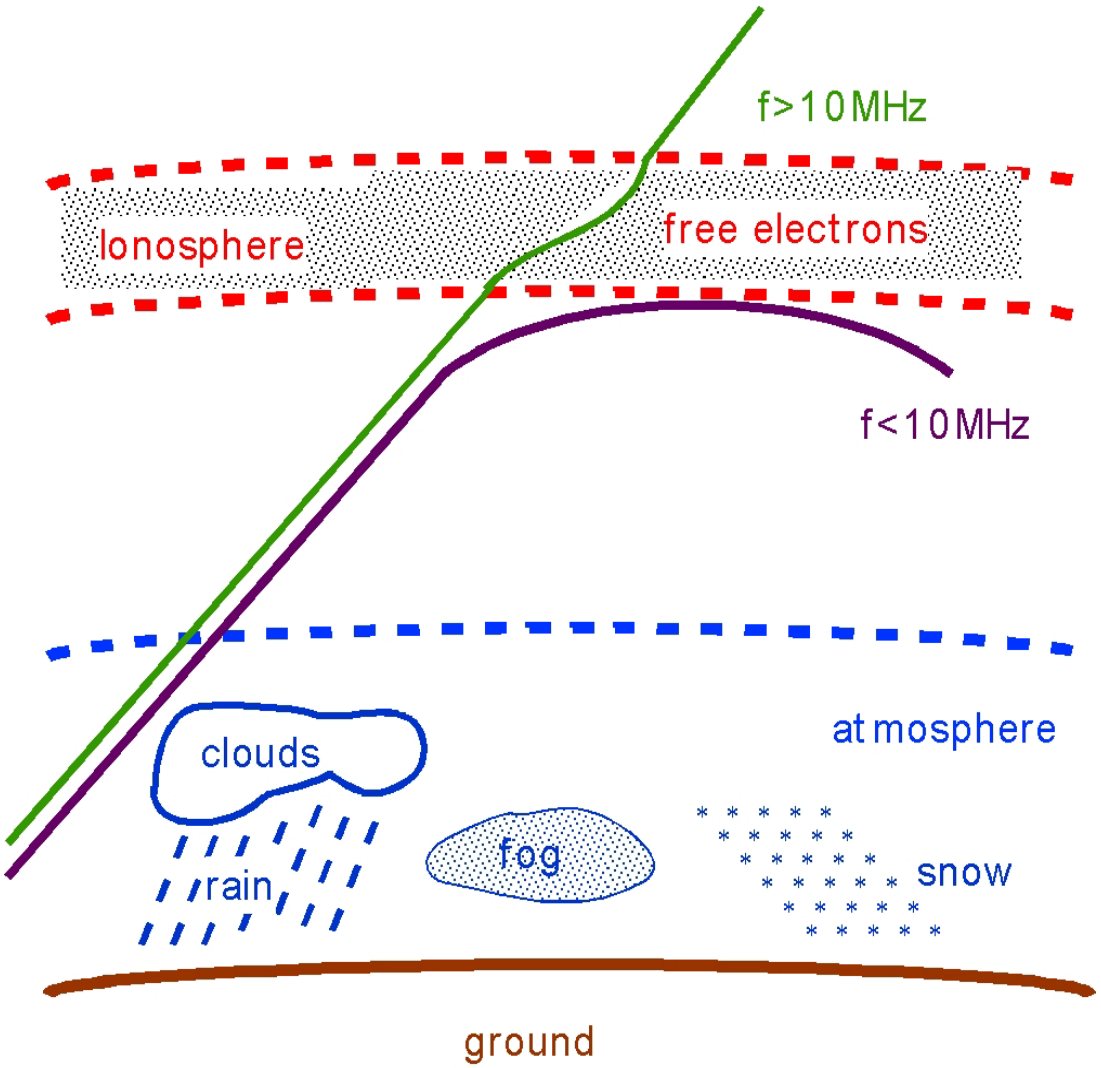
Atmosphere


Attenuation (dB/km)
100
40
20
10
4
2
1
0.4
0.2
0.1
0.04
0.02
0.01
0.004
0.002
0.001
Sea level
H_2O
9150 m altitude
O_2
O_2
H_2O
H_2O
10
15
20
25
30
40
50
60
70
80
90
100
150
200
250
300
400
Frequency (GHz)

Noise


1000
100
10
1
DEGREES KELVIN
GAL. LAT. |b| = 10°
|b| = 90°
NON-THERMAL BACKGROUND
H
OH
QUANTUM LIMIT, hν/k
2.76 K COSMIC BACKGROUND
.1
1
10
100
1000
ν (GHz)

Propagation



Link with Mars

- Mars Pathfinder Mission : 1996
- Distance Earth-Mars : 228’000’000 km

Friis formula:

$$P_r = P_f \cdot G_1 \cdot G_2 \cdot (\lambda/4\pi L)^2$$

From Earth to Mars

- Frequency : 7.175 GHz (λ = 41.8 mm)
- Terrestrial Antenna Gain : 4’265’795
  - Ø = 70 m
- Satellite Antenna Gain : 13.8
- Emitted Power on Earth : 22 kW
  - (a very small car)
- Received power on Mars : 3.16 10^{-16} W
  - (Not really much)

From Mars to Earth

- Frequency : 8.425 GHz (λ = 35.6 mm)

- Terrestrial Antenna Gain : 25’118’864
- Satellite Antenna Gain : 141

- Power emitted on Mars : 13 W
  - (a low consumption halogen lamp)

- Received power on earth : 7 .10^{-18} W
  - (nothing !!)

Properties of microwaves

- Directivity of the antennas
- Reflections on obstacles
  - Effective surfaces, radar
- Interaction with matter
  - Heating, measurement
- Non ionizing radiation
  - causing no mutation
- Stable oscillation frequencies
  - Atomic clocks and frequency references

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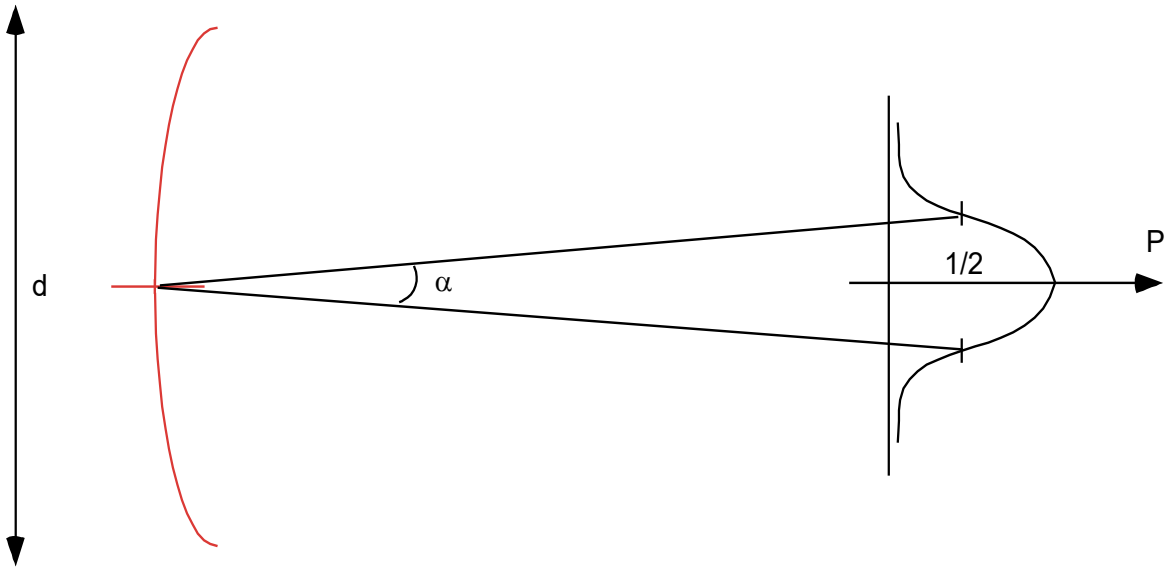
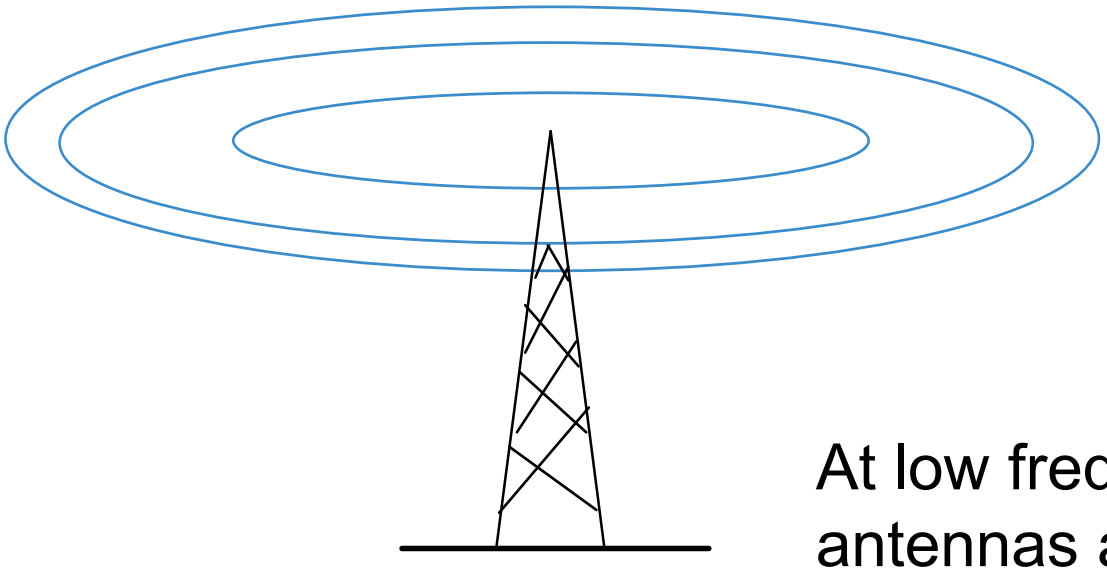
Directivity of antennas



$$\alpha \geq \frac{\lambda}{d}$$

Directivity of antennas



At low frequencies
antennas are omnidirectional

Directivity of antennas

At high frequencies, antennas are directive

Arecibo dish antenna

diameter: 305 m !

Arecibo beamwidth

- 50 MHz, λ=6m and α=1.12°
- 10GH, λ=3cm and α=0.0056°

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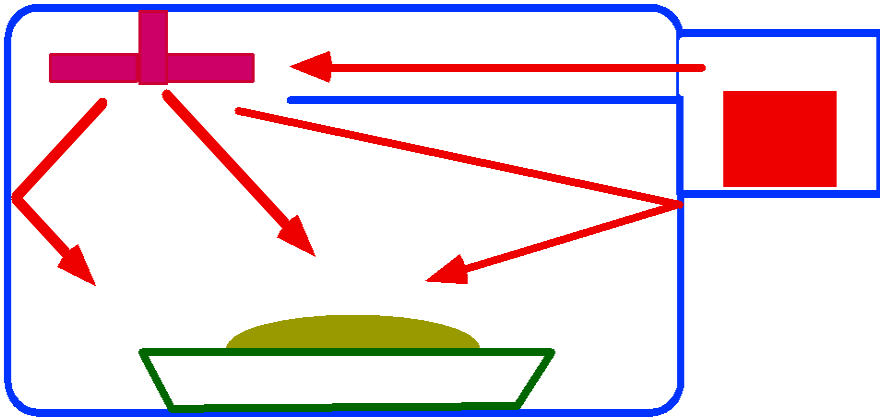
Interaction with matter : microwave heating

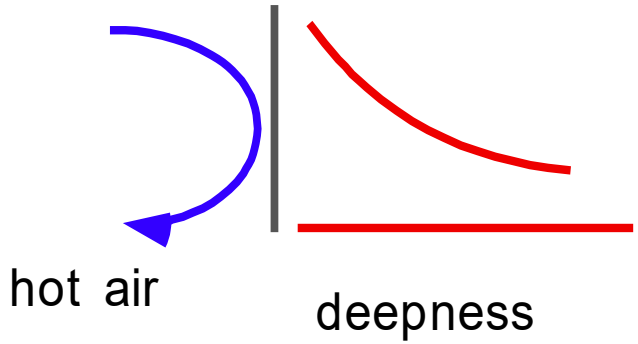


The waves penetrate into the matter and generate heat inside

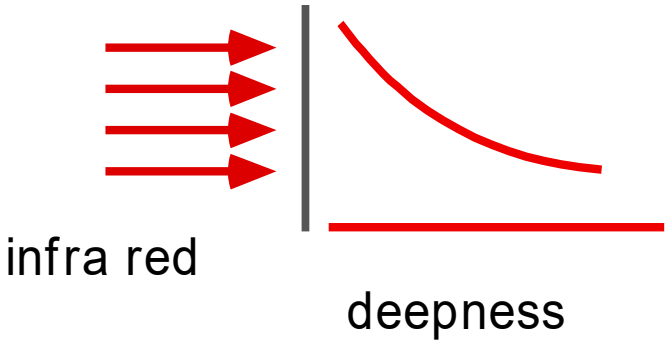
Interaction with matter : microwave heating

- Applicators :
  - Cavities
  - Progressive Wave
  - Slow wave
  - Antenna
- Principle :
- The wave is absorbed by the water. The absorption decreases when T increases

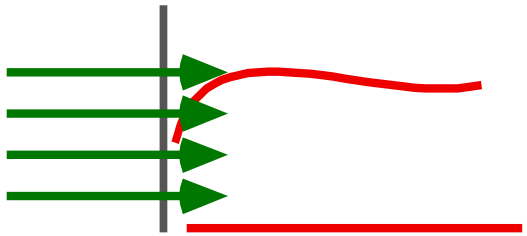
Interaction with matter : microwave heating



Convection



Conduction



microwaves

Interaction with matter : microwave heating. Advantages

- Good efficiency (50% of power transfer to the element which is heated)
- Selective heating
  - cereals or insects
  - electrons and ions
- Moderate cost and maintenance
- Less storage room needed as the heating cycle is shorter
- Less losses in the process
- No pre-heating needed

Interaction with matter : microwave heating. Drawbacks

- Costly to develop
- Impossible to grill
- Difficult to evacuate certain solvents needed in the printing industry
- Needs skilled workforce
- High security needed

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Biological effects : ionization

molecular cohesion energy

Type	*kJ/mole*	*eV/atom*
ionic	750	7800
dipolar	~20	207
Van der Waals	10	103
covalent		2,5

In microwaves, the energy of a photon is :

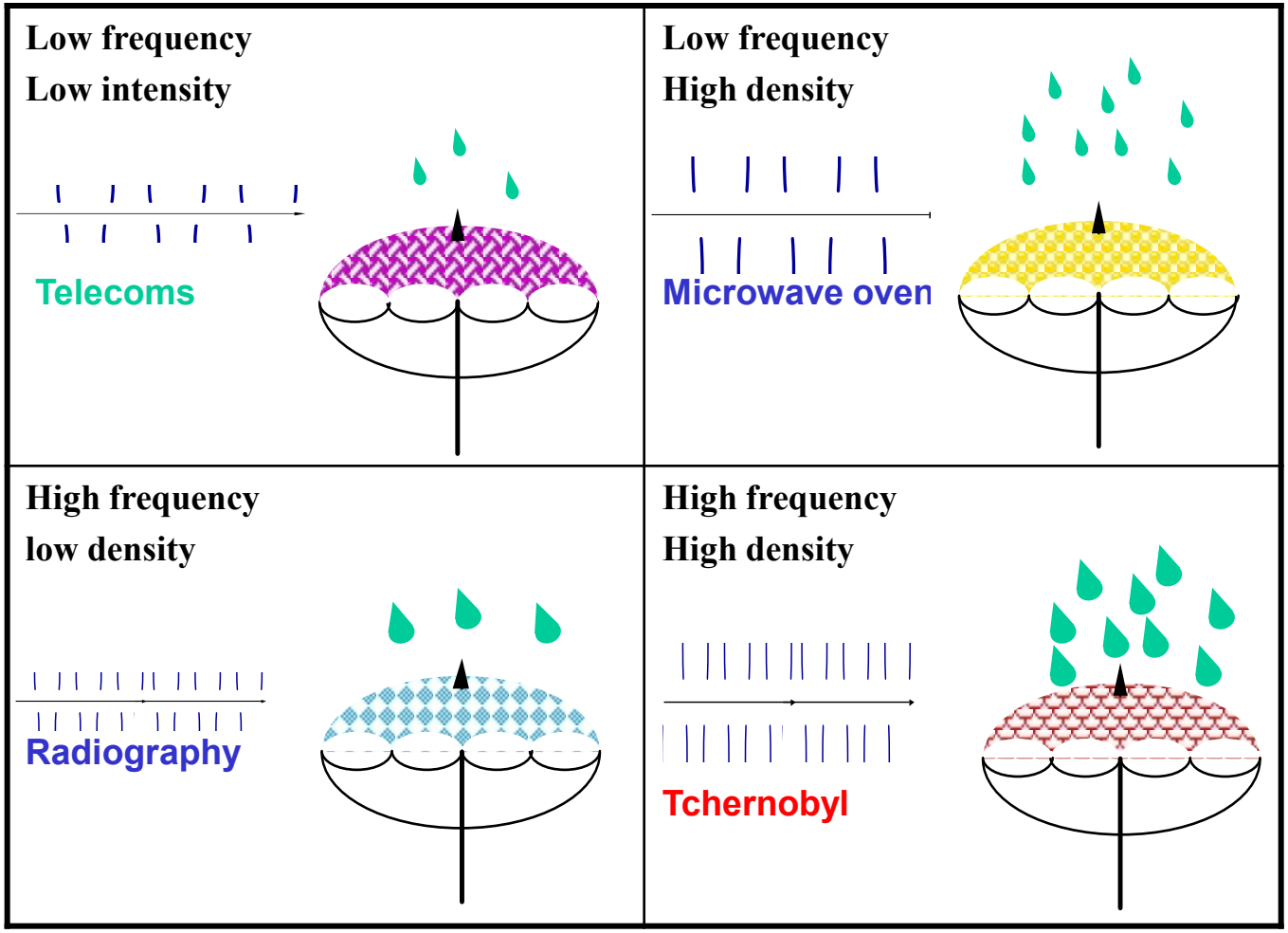
$1{,}2\ 10^{-6}$ to $1{,}2\ 10^{-3}$ eV

Biological effects : Thermal effects

- Limits exist since many years
  - USA : ~10 mW/cm2 = 100 W/m2
  - Russia : ~ 10 µW/cm2 = 0.1 W/m2
- Diathermy : 1-10 kW/m2 !!
- Solar flux : 1 kW/m2 (at ground level)

Analogy Electromagnetic waves = Rain

Frequency = size of drops ; Power = density of drops



Biological effects : non thermal effects

- Controversial since 30 years
  - Do they exist ? (probably yes)
  - Are they harmful ? (probably no)
- In doubt :
- Lower the acceptable limits