Systems and Equipment for Radio Communications

Ș.l. Alexandru Marțian, PhD

martian@radio.pub.ro

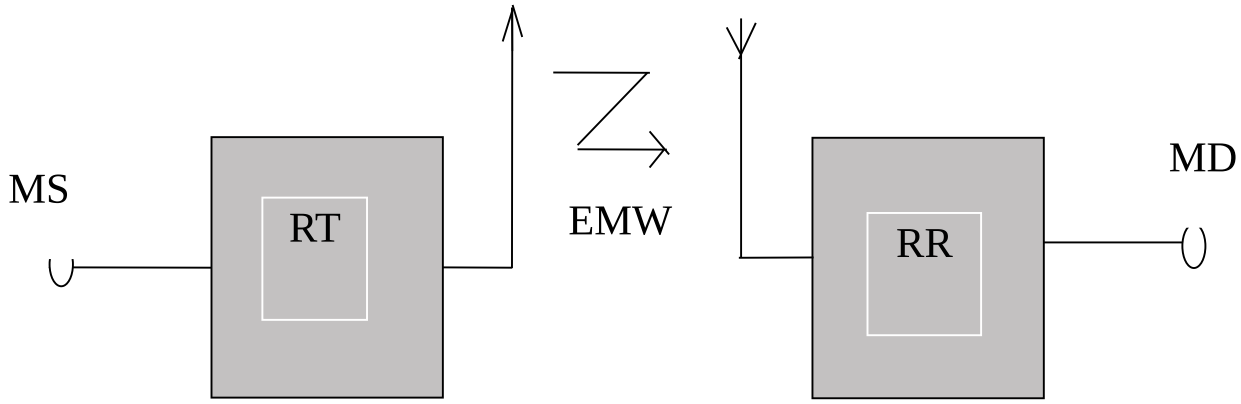
1. General Concepts

- The specific features of RC:

Messages are transmitted by using the propagation of the electromagnetic waves (EMW) in the RF range:

- The frequency range: $3*10^4$.....$4*10^{10}$ Hz

- The simplest RCS provides a one-way radio link between two points (nodes).



- By means of RCS one can deliver RC services:
  - Broadcasting;
  - Mobile communications;
  - Fixed communications.
- Service provider – user:
  - Network operator;
  - Service distributor;
  - Final user.

- The radio links/connections can be:
  - one way;
  - two-way:
    - simplex;
    - duplex;
    - simplex using two frequencies;
    - halfduplex (half/full).

- At present most of the RCS are structured in Radio Communications Networks (RCN), in other words, in complex systems where the radio links can be established between random points (nodes).

- We have to emphasize that nowadays most of the RCN are integrated as sections in complex communications systems;

- Besides RCN sections, these systems include also cable sections, optical fiber sections, etc.

- If one considers the fact that the configuration of the network is permanently the same or it changes in accordance with the user requirements the networks can be divided into:

  – stable networks

  – switched networks.

- E.g.:
  - Conventional radiotelephony: one or two radio channels are asigned to a group of users.
  - Celular radiotelephony or trunked radiotelephony: a group of radio channels is assigned and the members of the group use the channel that is available at the moment when he initiates a communication link.

- According to the scope of the transmission the RCN can be divided into:
  - Point to point;
  - Point to multipoint;
  - Broadcasting networks;
  - Data collecting networks;

- E. g.: audio and television broadcasting networks, radiopaging networks, meteorological data collecting networks, etc.

1.2 Radio Channels

- We have used the concept of radio channel; what do we mean by this concept?

- The frequency domain is divided into narrow bandwidths in accordance with the type of modulated signal; more and more systems use a division in the time domain too;

- the radio channel consists of: entities obtained as mentioned above, the transmission media and a part of the equipment that makes possible the use of the communication resources;

- Often, the notion is used to mention the frequency and/or time slots, the other elements going without saying;

- In the case of RCS the transmission media is, as a rule, the air, the atmosphere where the waves do propagate.

- That’s why it is important to remind some salient features of the atmosphere.

- The atmosphere is a complex media.

- In contrast with the metallic cables or wave guides, this media can not be optimized; it must be accepted as it is.

- As a whole the atmosphere consists of three major layers: troposphere, stratosphere, ionosphere;

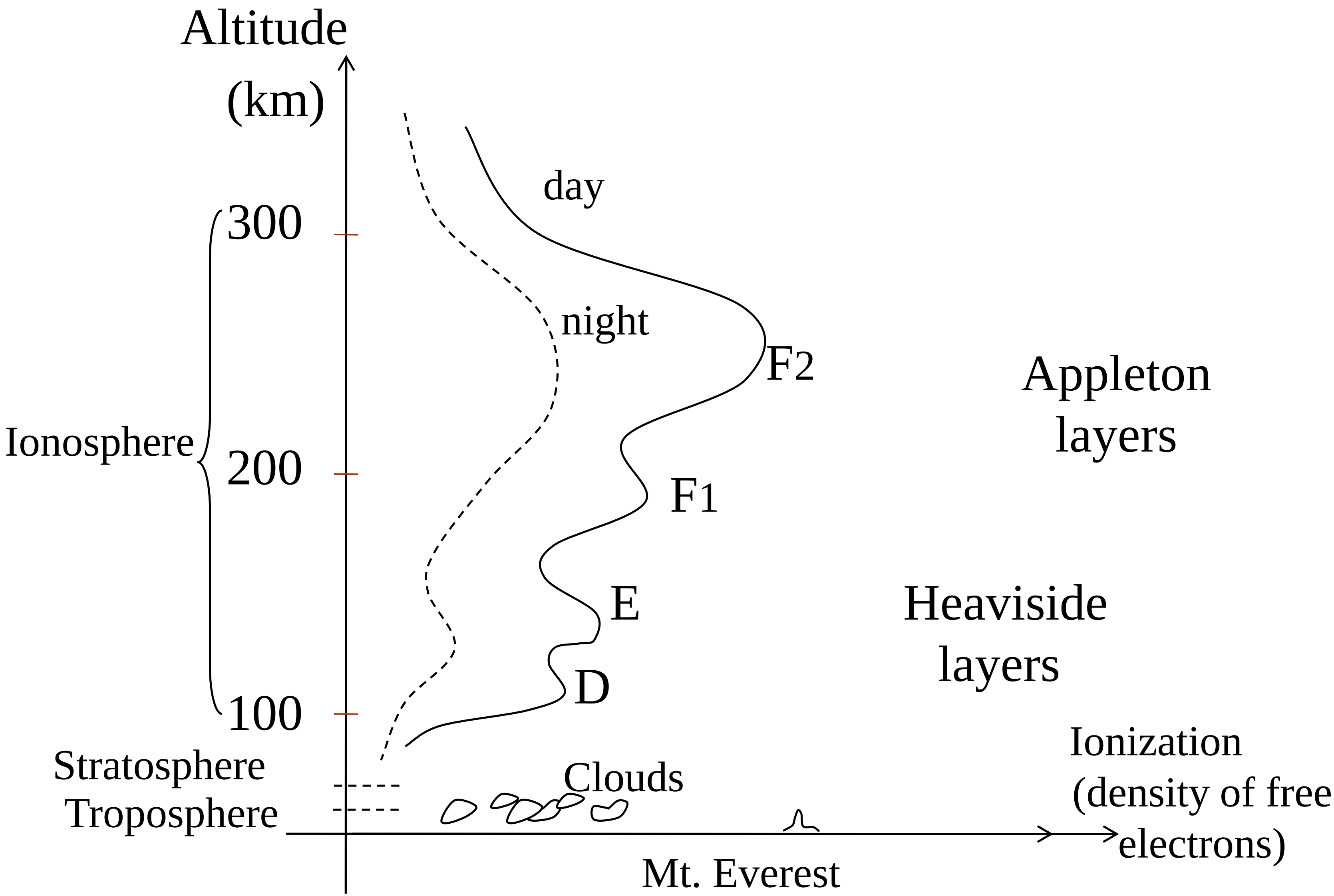
- *Troposphere* (h<15 km); it is remarked by the fact that here one finds: turbulences (winds), water vapors (the clouds) and a height diminishing temperature.
- The refraction index falls slowly with height and the EMW trajectories bends themselves toward the earth;

- *Stratosphere* (15..40 km); no water vapors, the temperature continues to diminish before becoming stable.

- I*onosphere* (40 .. 500 km); consists itself of more layers; the ionization of each layer depends very much on the hour during the day, on the season, on the solar activity, etc.

- This layer has an important contribution in the propagation of the RF EMW especially in the HF range.

- It influences very much this process by means of reflection, refraction, absorption of the RF waves.


Altitude
(km)
300
200
100
Ionosphere
Stratosphere
Troposphere
day
night
F2
F1
E
D
Appleton
layers
Heaviside
layers
Clouds
Ionization
(density of free
electrons)
Mt. Everest

1.3 Radio Waves

1.3.1 Introduction

- Radio Waves – a sub-domain of Electro-Magnetic Waves (EMW):

  Hertzian Waves – infrared waves - optical waves - ultraviolet waves - x rays – cosmic waves ;

- The range of interest: Hertzian Waves

  $(3*10^3...3*10^{12})$Hz;

- RC uses only a small part of this spectra, the so-called Radio Waves $(3 \cdot 10^4 - 4 \cdot 10^{10})$ Hz

- The RF range is divided in sub-ranges according to the value of the frequency or of the wavelength :

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

- As far back as the beginning of the RC, the specification of the frequency ranges and the frequency bandwidths as well as the allocation of them to different services and users were established by *international conventions* .

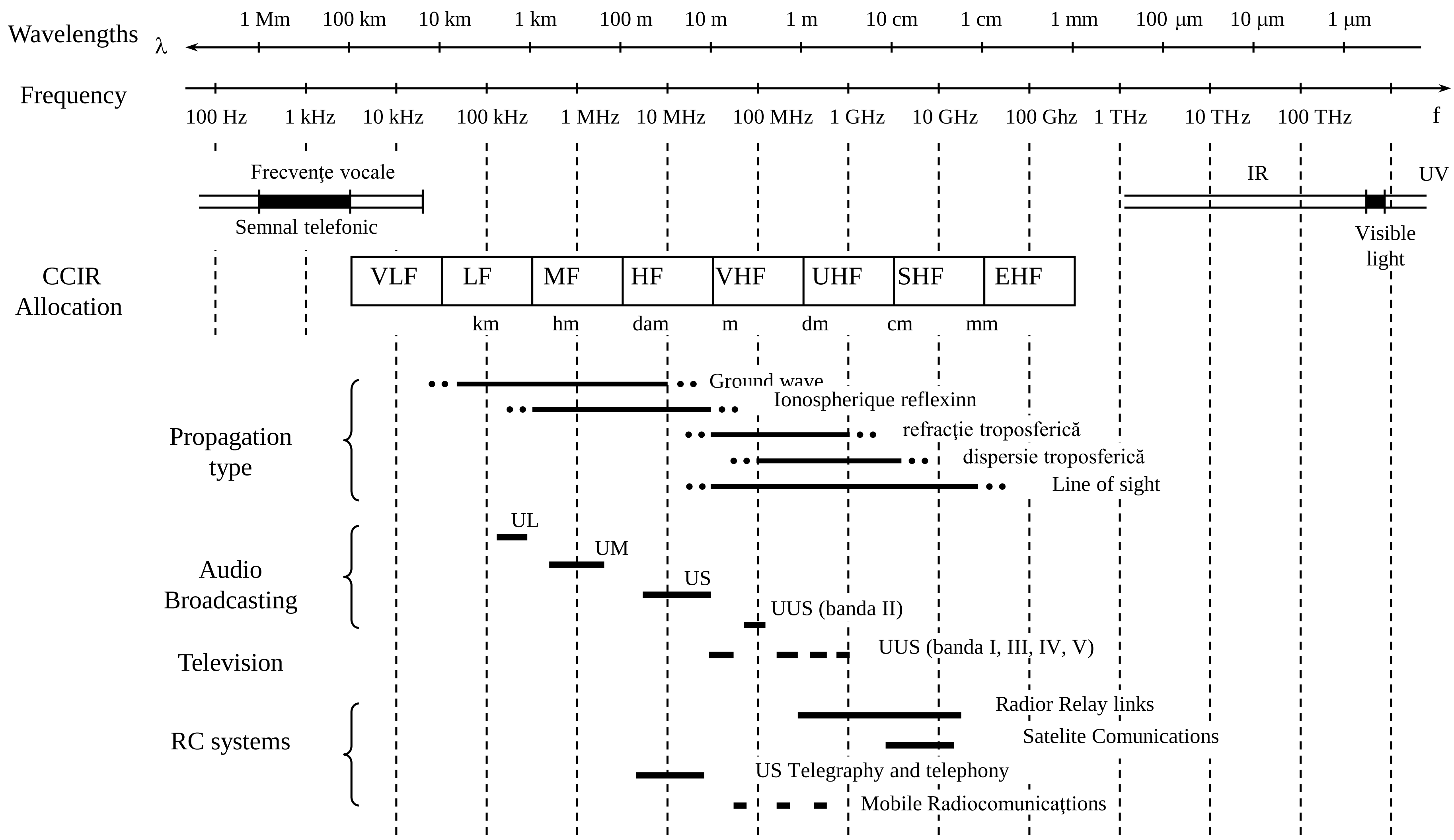
- 1865 - Paris – the first conference of *Union Telegraphique Internationale* (UTI);

- 1947 - *International Telecommunication Union* (ITU) was funded under the aegis of UNO.

ITU:

- Based in Geneva, Switzerland;

- Comprises three sectors:
  - ITU-R – Radiocommunication
  - ITU-T – Standardization
  - ITU-D - Development



Sub-ranges of RF spectrum established by IFRB

Hertzian Waves-Frequencies bandwidths

Nr.	Frequency	Designation	Abbreviation
4	3 ÷ 30 kHz	miriametric waves	VLF
5	30 ÷300 kHz	kilometric waves	LF
6	300÷3000 kHz	hectometric waves	MF
7	3 ÷ 30 MHz	decametric waves	HF
8	30 ÷300 MHz	metric waves	VHF
9	300÷3000 MHz	decimetric waves	UHF
10	3 ÷ 30 GHz	centimetric waves	SHF
11	30 ÷300 GHz	milimetric waves	EHF
12	300÷3000 GHz	decimilimetric waves	-

- Let note that the mentioned sub-ranges have specific propagation properties.

- As it was mentioned many times, in order to be transmitted, the message modulates a RF sinusoidal signal (carrier signal, carrier frequency f_1).

- The modulated signal has a frequency bandwidth.

- So that for a radio link a frequency bandwidth must be asigned and not only a frequency;
- The parameters of the bandwidth depends on the type of the modulated signal;

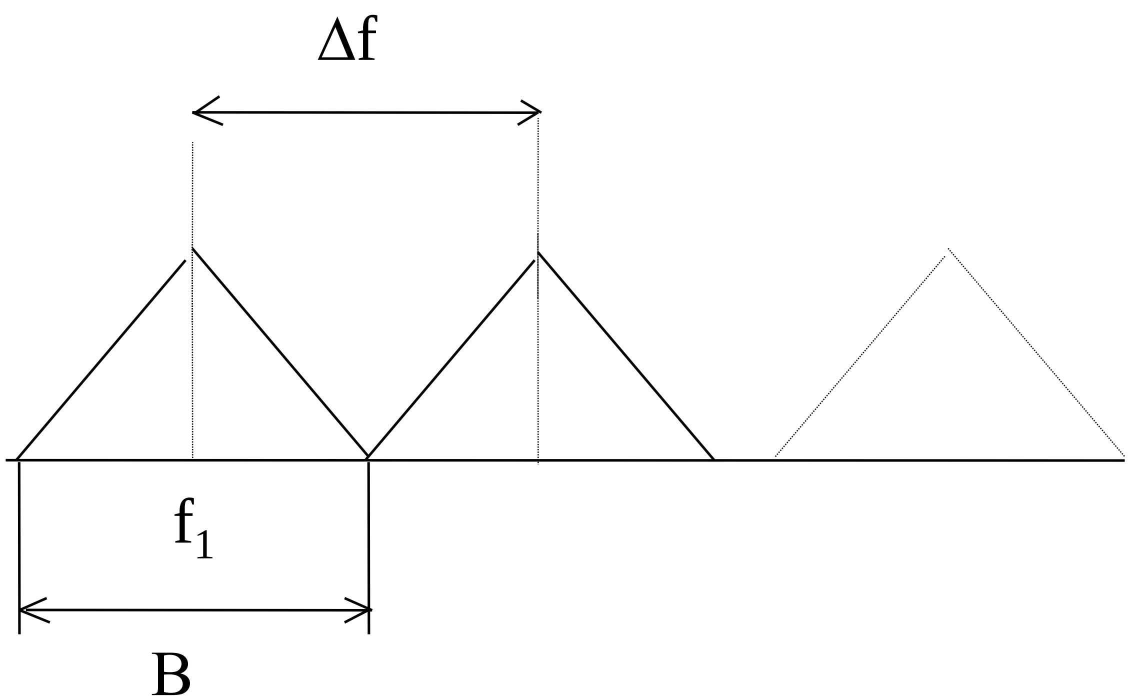
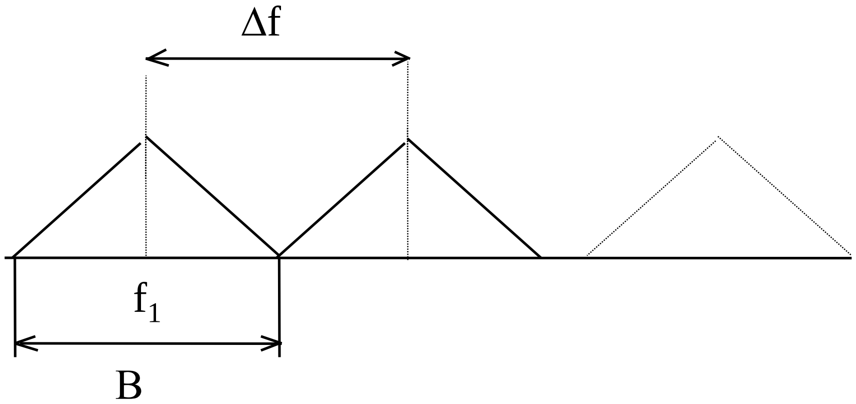


Fig. 1.3.1



E.g.:

- AM signals B = 9 kHz Δf = 9 kHz
- FM signals, B =200 kHz Δf= 200kHz
- Narrow band FM signals, B = 20 kHz Δf = 25 kHz
- SSB / AM - B =3,4 kHz Δf = 4 kHz
- etc.

1.4 The allocation of the frequencies (frequency bands) to form radio channels

- In the process of RF spectrum allocation one can identify more levels:
  - The allocation of the RF spectrum for different services;
  - The allocation of the frequency channels to different network operators;
  - The assignation of the radio channels in the frame of an RC network.

- In this section we are interested in the first level.

- To ensure the coexistence of different services the allocation and use of frequency are made according to international regulations issued by CCIR and IFRB.

- Having in mind the quite rapid attenuation of most signals, the RF spectrum is reused in more places on the globe;
- To do that the globe surface is splitted in 3 regions and a few zones:
  - The first Region: *Europe - Mongolia – Middle Orient (IRAN) – Turkey – Africa;*
  - The second Region: *Australia – South-East Asia – Pacific area*;
  - The third Region: *America + Greenland*.

Example of frequency bandwidth allocation in the first region:

- Frequency range 130÷285 kHz

Bandwidth	Service
130-150	- Maritime Mobile
	- Fixed
150-160	- Maritime Mobile
	- Sound broadcasting (by special agreements)
160-255	- Sound broadcasting
255-285	- Sound broadcasting
	- Maritime Mobile
	- Aeronautical Radionavigation;

- Frequency range 285÷525 kHz:

Bandwidth	Service
285-315	-Maritime Radionavigation (Radiobeacons)
	- Aero. Radionavigation
315-405	- Aero. Radionavigation
405-415	- Aero. Radionavigation
	- Maritime Radionavigation
415-490	- Maritime Mobile
490-510	- Mobil (emergencies and radiopaging call)
510-525	- Maritime Mobile
	- Aero. Radionavigation

- These allocations can be found in the CCIR norms and standards;
- Each country has its own national table for frequency allocation, available on the internet:

  - For Romania, the TNABF – Tabelul Național de Alocare a Benzilor de Frecvență:

    http://www.ancom.org.ro/tnabf_3998

- ***The Fixed Service*** is an RC service that allows radio links between fixed points to be provided (E.g.: the fixed aeronautical service transmits messages related to the navigation of aeroplanes).

- ***The Mobile Service*** is an RC service that allows radio links between fixed nodes and mobile nodes or between mobile nodes to be provided.

- ***The Broadcasting Service (B);*** signals modulated with audio messages are transmitted in order to be received directly by a great number of users;

- The purpose of RC systems providing broadcasting service is to transmit news and cultural content by means of high quality transmissions;

Tabelul 1.4.1 Frequency Ranges Used in Sound Broadcasting RC

Frequency range	Name	Type of transmission
150 ÷ 285 kHz	LW	AM
525 ÷ 1605 kHz	MW	
3,20 ÷ 3,40 MHz	SW	
5,95 ÷ 17,90 MHz		
21,45 ÷ 26,10 MHz		
87,5 ÷ 108 MHz	USW	FM

- Main features of the broadcasting frequency ranges:

Medium Wave (MW)

- Propagation take place mainly as ground wave (direct wave).
- Reflections appear at the layer D of the ionosphere and is accompanied by a strong absorption during daylight.
- That’s why the quality of the long distance transmissions during the night is better than the ones realized during daylight.

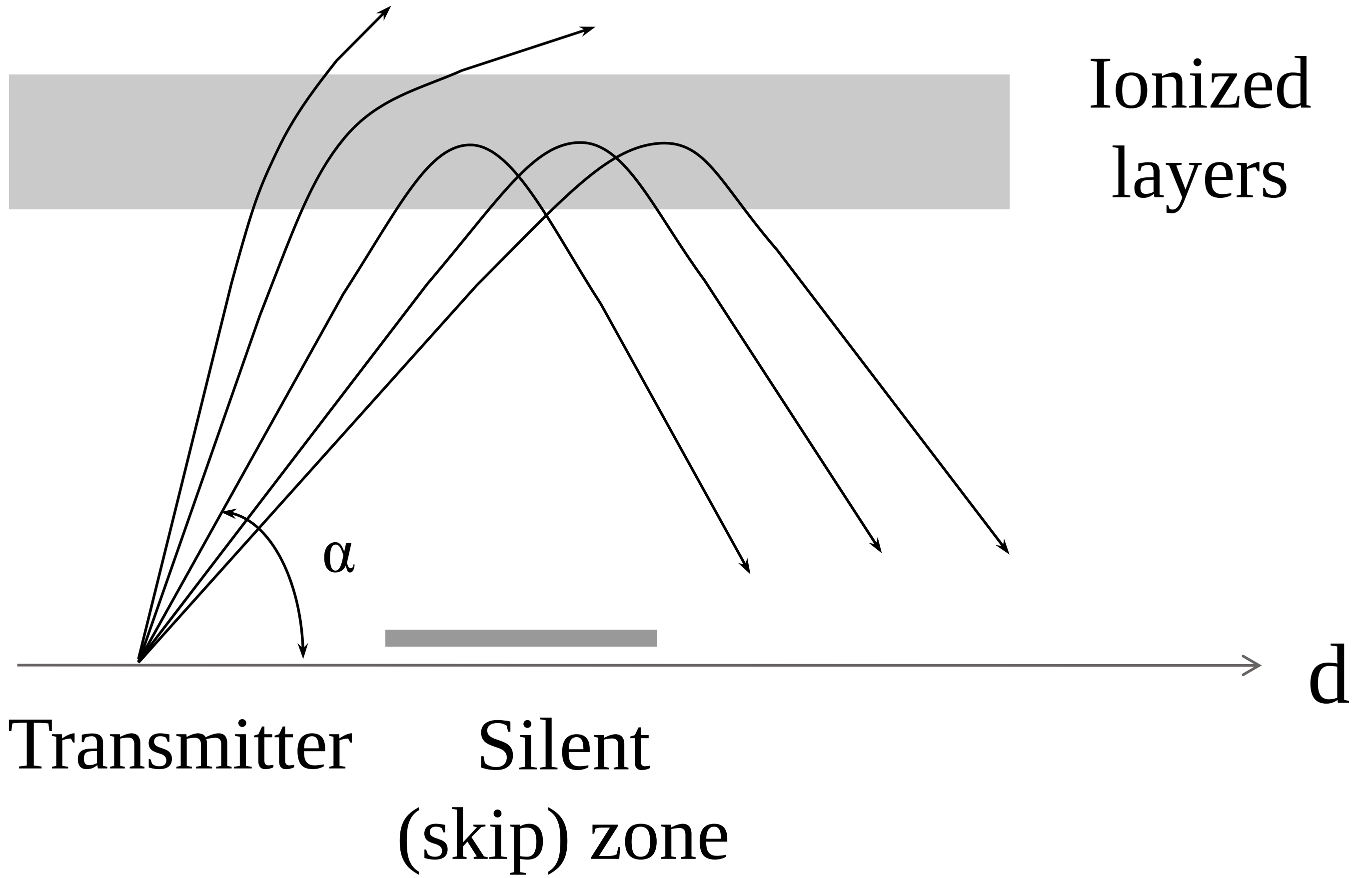
Short wave (SW)

- At short distance the most important component is the ground wave; By using multiple reflections on the ionosphere one can obtain transmissions at very long distances.
- Sometimes, the reception is affected by the interference between the direct and the reflected waves (fading) and by the modifications of the propagation conditions influenced by the changing parameters of the ionosphere; the received signal fluctuate very much.

- The reflection is due to the variation of the refraction index *n* in the various ionized layers;

- When the angle of the wave rises the reflected wave reaches the ground closer to the transmitter. If the angle is very large the reflexion doesn’t take place;

- The so called silent zone; the radius of this area depends on the frequency;



Frequency	Silence Area Radius
15 MHz	2000 km
25 MHz	5000 km
>30 MHz	no more reflection

Ultra Short Waves (USW)

- The range USW (41 MHz ÷ 960 MHz) is divided in five disjunct sub-ranges: one for audio broadcasting (FM modulated) and four for TV broadcasting (VSB modulated).

- The transmission is done only by direct wave (Line of Sight- LOS)
- This solution is reserved for regional coverage.

1.5 Receiving and Transmitting Aerials (antennas)

- Radiotransmitter delivers as output an electric signal; the power of this signal: P_e.
- The electric signal is used as input of the transmitter aerial; around the aerial a EMF results that fulfils the requirements to propagate as EMW.
- At the receiving point the inverse process takes place; the power of the receiver input electric signal is P_r.

- The aerials could be considered as transducers that convert the electric signals to EMW.
- Consequently one can identify two types of antennas: transmitting and receiving antennas.
- We can identify differences between them but these are mostly of structural nature.
- It was demonstrated that the main parameters of an antenna are the same either it is used as a transmitting one or as a receiving one. (*the reciprocity theorem)*.

- The simplest antenna, theoretically speaking, is *the isotropic antenna*.

- The power density of the EMW at the distance *d* from such an antenna, used as a transmitting antenna, can be calculated as:

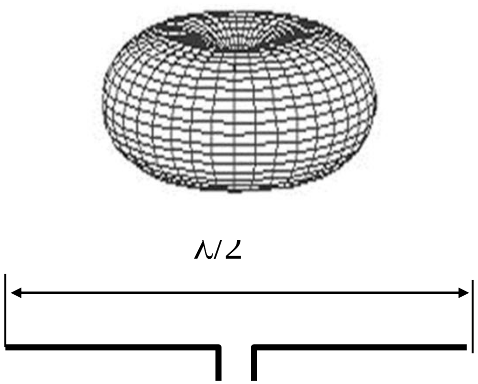
$$p_0 = \frac{P_E}{4\pi d^2} \qquad \left(W / m^2 \right)$$

- In the case of a real antenna the power density depends on the direction – directional antenna ;
- For a given direction α one can define the antenna gain as:

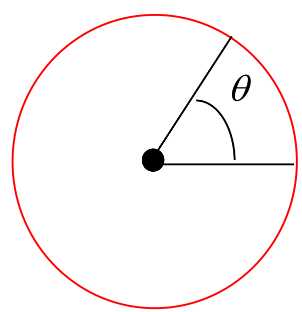
$$g_{\alpha} = \frac{p_{\alpha}}{p_0} \qquad G_{\alpha} = 10\lg\frac{p_{\alpha}}{p_0}\ dB$$

- One can represent the g_{α} parameter versus the direction. The surface resulted this way represents the radiation diagram (pattern) of the antenna;

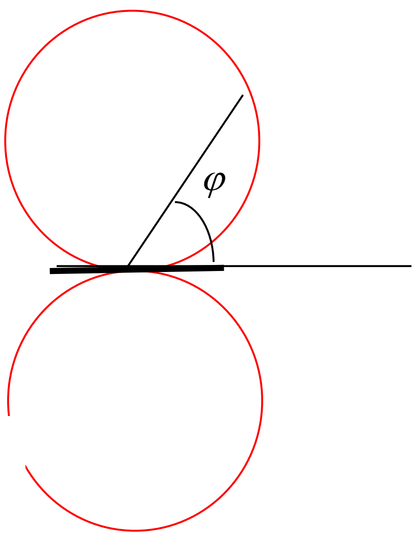
- The graphical representation of such a surface is quite difficult;
- A simpler way is to represent two sections through the surface obtained by means of two right angled planes;
- E.g: The dipole antenna:



a.

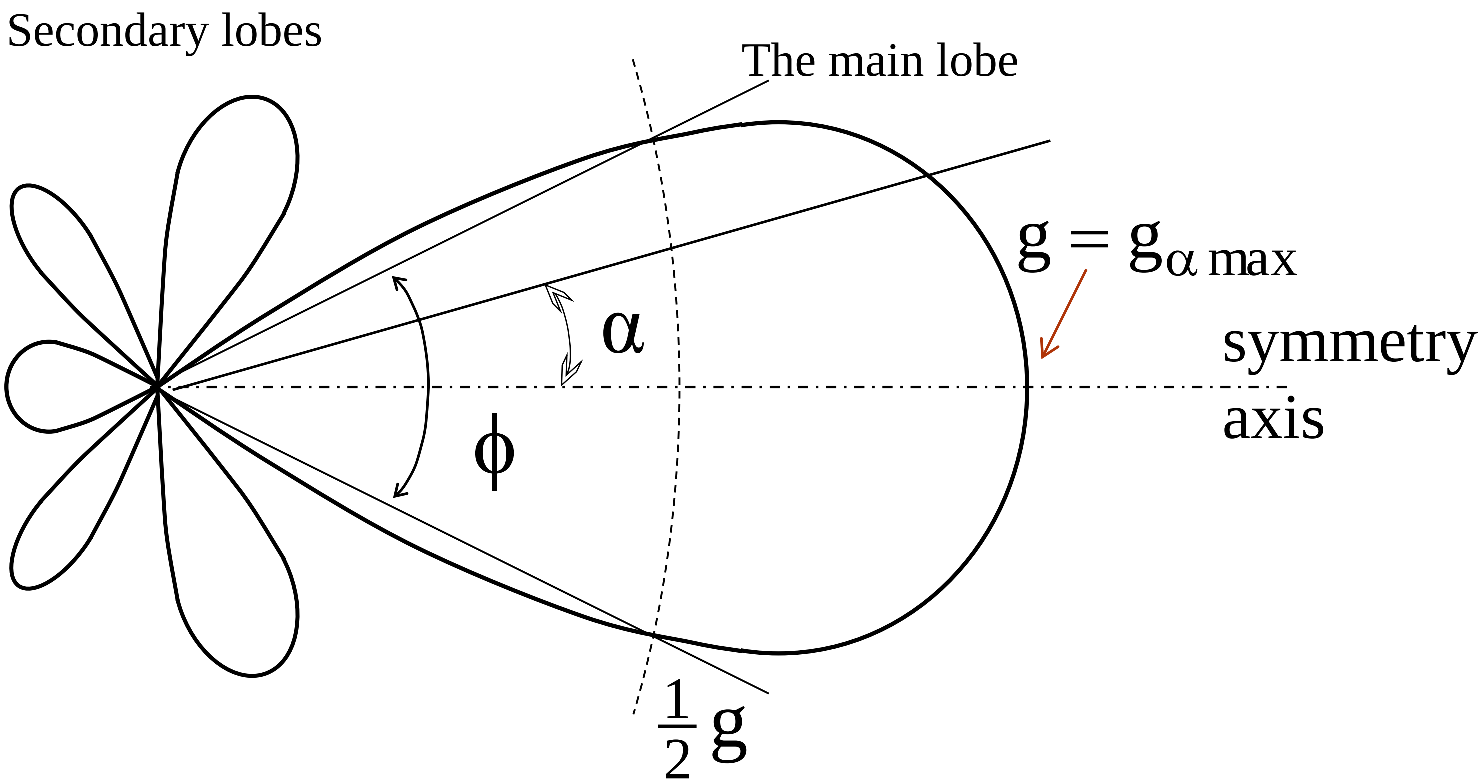


b.



c.

- Another example: the radiation pattern of an antenna with axial symmetry:



- The antenna gain can be defined as:

$$g = g_{\alpha \max}$$

- For an omnidirectional antenna the gain is equal to 1.
- For the directional ones the gain is larger than 1;
- Antenna efficiency – a measure of the efficiency with which a radio antenna converts the radio-frequency power accepted at its terminals into radiated power.

- In the case of the receiving antennas: *the effective area* or *effective aperture* of the antenna;

- A match-terminated antenna (characteristic impedance) delivers an output power, P_r, proportional to the EMW power density in the receiving zone, p_r

$$A_{ef} = \frac{P_r}{p_r} \quad (m^2)$$

- It can be proven that the effective area of an isotropic antenna is:

$$A_{0ef} = \frac{\lambda^2}{4\pi}$$

- Directional antennas – the effective area depends on the EMW arriving direction - $A_{ef\beta}$.

- The maximum value corresponds to the optimal arriving direction - A_{ef} .

- It can be demonstrated that the maximum value is proportional to the antenna gain:

$$A_{ef} = g_r \bullet A_{0ef}$$

1.6 The power budget of an RC system and some quality parameters

- The most important factor that influences the distance between two nodes engaged in an RC transmission is the propagation loss;

$$a = 10\lg\frac{P_E}{P_R} \quad (\mathrm{dB})$$

- If the system uses isotropic antennas :

$$P_{R0} = A_{ef\,0}\, p_0 = \frac{\lambda^2}{4\pi} \cdot \frac{P_E}{4\pi d^2} \;\Rightarrow\; a = \left(\frac{4\pi d}{\lambda}\right)^2$$

- In a logarithmic form the free space loss can be written as (*Friis equation*):

$$a_0 = 20\lg\left(\frac{4\pi\, d}{\lambda}\right) = 92{,}4 + 20\lg d\left[km\right] + 20\lg f\left[GHz\right]\left(dB\right)$$

- Of course this is a *minimum optimistic value* – considering a free, lossless propagation media.

- There are many causes rising the loss:
  - the effect of the landforms,
  - the effect of the atmosphere; the features of the atmosphere depends on the meteorological phenomenon; the meteorological phenomenon depends on the propagation route;
  - the interference caused by other signals, etc.

- In the case of the directional transmitting/receiving antennas it can be obtained:

$$P_R = A_{ef}\, p = A_{ef} \cdot g_{E\alpha} \cdot p_0 = g_{R\beta} g_{E\alpha} \cdot \frac{\lambda^2}{4\pi} \cdot \frac{P_E}{4\pi d^2}$$

$$a = 20\lg\left(\frac{4\pi d}{\lambda}\right) - 10\lg\left(g_{R\beta}\right) - 10\lg\left(g_{E\alpha}\right) = a_0 - G_{R\beta} - G_{E\alpha}$$

- If we consider the antennas optimally deployed and we introduce the connecting cables losses too, it results:

$$a = a_0 - G_R - G_E + a_{pRF}$$

- In a logarithmic form:

$$10\lg P_R = 10\lg P_E - a_0 + G_E + G_R - a_{pRF}$$

- This equation represents the so/called free space RCS power budget.

- The received signal is modified also due to:
  - ❖ The noise introduced in the transmission channel;
  - ❖ Distortions generated during the signal processing having in mind actual circuits;
  - ❖ The lack of the reciprocity between the modulating and demodulating functional blocks;

- Consequently, the recovered message differs from the transmitted one:

$$m_r(t) \neq m_e(t)$$

- To evaluate the performance of the radio communication system from this point of view one can use several parameters:

- For Analogue Communications Systems (ACS):
    - *the average squared error*,

$$\varepsilon = \overline{\left[m_e(t) - m_r(t)\right]^2}$$

    - the *Signal to Noise Ratio* (SNR),

$$\frac{S}{N} = \frac{\overline{m_r^2(t)}}{\overline{n_r^2(t)}}$$

- For Digital Communications Systems (DCS) the *error rate*, that is the probability that a symbol is wrongly decoded.

1.7 Some of the RCS parameters

1. Frequency bandwidth:

- allocated
- necessary
- taken (occupied).

2. Frequency:

- f_a – allocated frequency - the central frequency of the allocated bandwidth
- f_r – reference frequency - a frequency having a precise relationship versus f_a
- f_e - transmission frequency - the central frequency of the taken bandwidth
- f_c - characteristic frequency - a frequency easily to be identified in the transmitted spectrum;
- δf – frequency tolerance (Hz,ppm).

- Radio transmitting specific parameters:

– *Unwanted (spurious) emissions* – transmitted power associated with one or more out of band frequencies, power that can be reduced by technical improvements that do not modify the quality of the useful signal;

– *Jamming* – represents the degradation of the quality of an RC transmission, or its repeated disruption caused by any kind of radio signal;

- There are some other parameters associated with the transmitter or with the receiver; they will be introduced in the appropriate section;

The Main Themes of the Lectures:

- Radiotransmiting Equipment;
- Radioreceiving Equipment;
- Frequency Synthesis (the Generation of the Carrier or Local Signals);
- Noise and Distorsions in Radio Communications Systems

Bibliography:

- I.Marghescu, Iancu Ceapă; Radioreceptoare,
- Mircea Ivanciovici: Echipamente de RE .
- Joseph Carr, The Technician’s Radio Receivers Handbook: Wireless and Telecommunications Technology, Newness, 2000
- Paul Young, Electronic Communications Techniques, Prentice Hall, 2004
- Faculty website: lectures support - **Moodle**;

- Evaluation for the final grade:
  - Tests during the lectures
    (2-3 tests of 5-10 minutes) 10p
  - Laboratory 30p
  - Partial exam 20p
  - Final Exam 40p

- Requirements to obtain a final grade >5:
  - Laboratory: >50%
  - Total number of points > 50 p

- The students with a good presence to the lectures can receive a bonus - in accordance with the lecture attendance - of maximum 10 points. These points are added only if the total number of points is >50.