UNIVERSITY OF WEST BOHEMIA

Faculty of Electrical Engineering
Department assigning the topic of the thesis

# BACHELOR'S THESIS

Measurement of Electromagnetic Field According to Health and Safety Legislation

Author: **Ignat Chestikov**

Supervisor: **Zdeněk Kubík**

2022

ZÁPADOČESKÁ UNIVERZITA V PLZNI
Fakulta elektrotechnická
Akademický rok: 2021/2022

# ZADÁNÍ BAKALÁŘSKÉ PRÁCE
(projektu, uměleckého díla, uměleckého výkonu)

| | |
|---|---|
| Jméno a příjmení: | **Ignat CHESTIKOV** |
| Osobní číslo: | **E19B0221P** |
| Studijní program: | **B2612 Electrical engineering and informatics** |
| Studijní obor: | **Electronics and telecommunications** |
| Téma práce: | **Měření elektromagnetických polí dle legislativy o bezpečnosti a ochraně zdraví** |
| Zadávající katedra: | **Katedra elektroniky a informačních technologií** |

## Zásady pro vypracování

1. Make a survey of current state of legislation and recommendations regarding health protection against non-ionizing radiation.
2. Study the available measuring instruments suitable for measuring electromagnetic fields.
3. Prepare a measurement methodology for available instruments.
4. Measure the electromagnetic field at selected locations.
5. Discuss the measured results and suggest possible improvements for suggested measurement methodology.

| | |
|---|---|
| Rozsah bakalářské práce: | **30 – 40** |
| Rozsah grafických prací: | **dle doporučení vedoucího** |
| Forma zpracování bakalářské práce: | **elektronická** |
| Jazyk zpracování: | **Angličtina** |

Seznam doporučené literatury:

1. Directive 2006/25/EC of the European Parliament and of the Council of 5 April 2006 on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation) (19th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). Available online at https://eur-lex.europa.eu/homepage.html
2. Recommendation and other documents of International Commission on Non-Ionizing Radiation Protection. Available online at https://www.icnirp.org/

| | |
|---|---|
| Vedoucí bakalářské práce: | **Ing. Zdeněk Kubík, Ph.D.**<br>Katedra elektroniky a informačních technologií |
| Datum zadání bakalářské práce: | **8. října 2021** |
| Termín odevzdání bakalářské práce: | **26. května 2022** |

Západočeská univerzita v Plzni
Fakulta elektrotechnická
L.S.

**Prof. Ing. Zdeněk Peroutka, Ph.D.**
děkan

**Doc. Ing. Jiří Hammerbauer, Ph.D.**
vedoucí katedry

V Plzni dne 8. října 2021

**Abstract**

This undergraduate thesis aims to present material on what an electromagnetic field is, its types and effects on the human body, examining health and safety legislation and measuring electromagnetic fields in accordance with it. The first part of the paper is devoted to an explanation of Maxwell's equations, then in the next part: an overview of the types of radiation. In the third chapter we turn to established legislation and establish hygienic limits and examine the types of exposure. In the final part we will take measurements at selected locations and evaluate the results based on the established norms.

**Keywords**

electromagnetic fields, Maxwell's equations, effects of electromagnetic fields on the human body, health and safety legislation

**Acknowledgements**

I would like to thank my supervisor Zdeněk Kubík for his invaluable help and the Department of Electronics and Information Technology for providing the measurement equipment.

# Content

# List of Symbols and Abbreviations

| Symbol | Description | Unit |
|---|---|---|
| | | |
| $H$ | magnetic field strength | (T) |
| $I$ | conduction current | (A) |
| $\Psi$ | finite dielectric flux | $(\frac{N \times m^2}{C})$ |
| $E$ | electric field strength | (V/m) |
| $\Phi$ | total magnetic flux | (Wb) |
| $c$ | randomly oriented closed loop | |
| $D$ | electric flux density | $(\frac{C}{m^2})$ |
| $\Gamma$ | closed surface | |
| $B$ | magnetic flux density | (T) |
| $\lambda$ | wavelength | (m) |
| $c$ | speed of propagation | (m/s) |
| $f$ | frequency | (Hz) |
| RMS | Root Mean Square | |
| $t$ | time | (s) |
| $G$ | body mass | (kg) |
| $C_b$ | heat capacity | (J/K) |
| $\Delta T$ | increase in body temperature | (℃) |
| $E$ | heat due to microwave irradiation | (J) |
| $M$ | heat due to metabolism | (J) |
| $S_b$ | body surface | $(m^2)$ |
| $\alpha_{ab}$ | heat transfer coefficient air - body | $(\frac{W}{m^2 \times K})$ |
| $\theta_{ab}$ | initial air - body temperature difference | (℃) |
| $H$ | heat sensation | |
| $P$ | given absorbed power | (W) |
| $P_0$ | absorbed power | (W) |
| EMC | electromagnetic compatibility | |
| EMF | Electromagnetic field | |
| EM | electromagnetic | |

# Introduction

These days, all mankind uses various electrical appliances and machines that make our lives more comfortable. Every home has a variety of home appliances; in offices, universities and schools one finds computers, scanners, printers and other office electronics that facilitate the working and learning process. Being outdoors, we may notice many different antennas. But we want to ask the question: do they all work within the prescribed limits?

The main objective of my bachelor's thesis is to measure the electromagnetic fields at selected locations and, based on the results, conclude that the strength of the electric field is below the established norms.

In order to achieve the objective, a number of tasks need to be carried out:

- study the directive,
- select suitable equipment,
- measure and analyze the results.

I will also cover topics such as:

- electromagnetic field,
- electromagnetic radiation,
- types of electromagnetic radiation,
- regulations,
- effects of electromagnetic waves on the human body.

The results of the investigation will help you to judge whether the chosen locations comply with the regulations.

# 1.Electromagnetic field

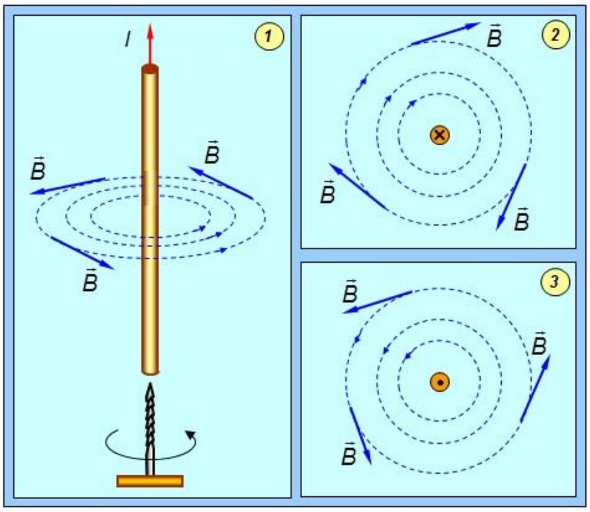
Firstly, we need to know: how does the electromagnetic field occur?

In 1865, James Clerk Maxwell presented the world with his theory of electromagnetic fields, which stated that if at any arbitrary point in space a magnetic field changes over time, then at the same point an electric field arises, also provided any closed conductor is in the field, then the arising electric field induces an induction current in it. From this theory, the opposite phenomenon can also be deduced: if the electric field changes over time, a magnetic field also arises at this point.

It follows from the above that an electric field and a magnetic field, when one is changed, produce the other, ultimately forming one single electromagnetic field.

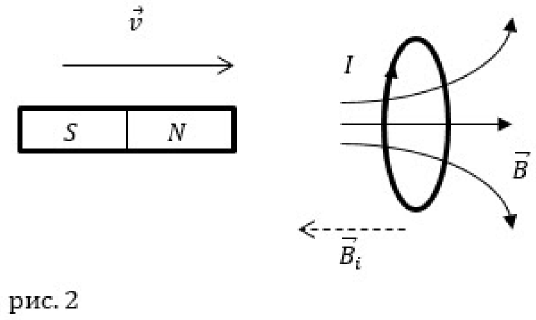
There are four Maxwell's equations:

$$\oint_{c} H \times ds = I + \frac{d\Psi}{dt} \quad (1)$$



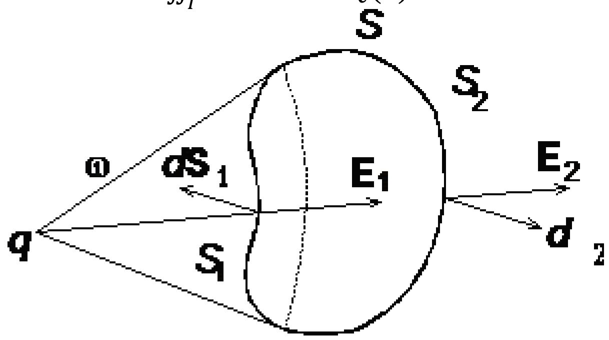

Pic.1 Magnetic field lines of an infinitely long rectilinear conductor with current[1]

$$\oint_c E \times ds = \frac{-d\Phi}{dt} (2)$$



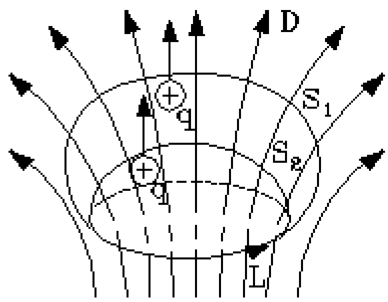

Pic. 2 Direction of external magnetic field[2]

$$\oiint_\Gamma D \times dS = Q (3)$$




Pic.3 Different Gaussian surfaces with the same amount of electric field vector flux[3]

$$\oiint_\Gamma B \times dS = 0 (4)$$




Pic.4 In an arbitrary magnetic field, two arbitrary surfaces are stretched on some contour[4]

Equation (1) expresses equality of the integral of the magnetic field strength H along a randomly oriented closed loop C and the total current, which is expressed by the sum of conduction current I and bias current d /d Ψ t, where Ψ is the finite dielectric flux. The second expression (2) defines a similar rule for the $E$ electric field strength, its integral over the same circuit is given by the negative value of the time-varying total magnetic flux Φ that passes through it. The following equation (3) proves that the total charge Q is equal to the integral of the electric flux density D that passes through the closed surface Γ. The last equation (4) the integral of the magnetic flux density B is zero.

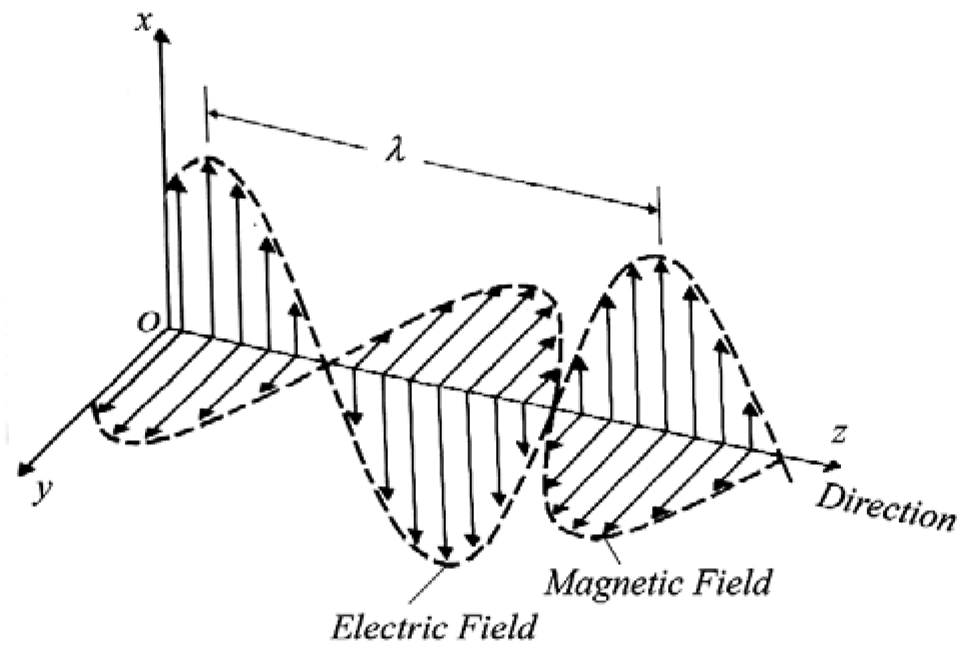
# 2.Electromagnetic radiation

Electromagnetic radiation or electromagnetic waves are the excitation of an electromagnetic field through space. Radiation is divided into different types of radiation in relation to wavelength, such as gamma rays, X-rays, ultraviolet radiation, visible light, infra-red radiation, radio waves and low-frequency electromagnetic oscillations.

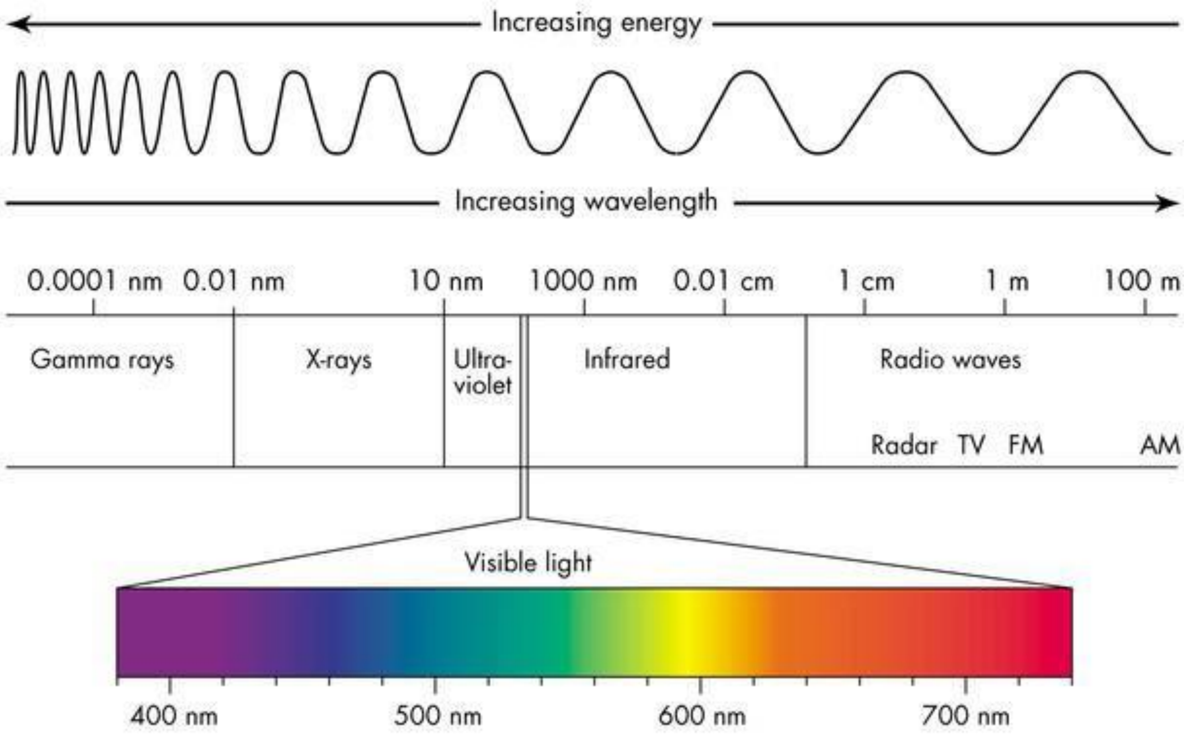
For all types of waves there is a single speed of propagation in space regardless of frequency, but the frequency itself varies in very wide ranges depending on the type of radiation, for low-frequency electromagnetic waves it is a few vibrations per second, and 1020 for gamma rays. Since the wavelength is given by the formula:

$$\lambda = c/f,$$

where $c$ is the speed of its propagation and $f$ is the frequency of oscillation, the wavelength can vary from a few thousand kilometers to $10^{-14}$ meters for X-rays.




Pic.5 Propagation of electromagnetic wave in free space [5]




Pic.6 Electromagnetic spectrum[6]

### 2.1 Types of electromagnetic radiation

Non-ionizing radiation is sub-grouped into frequencies (number of oscillations per second) or wavelength bands (distance between two peaks of an oscillation). This classification is not always used strictly and might differ depending on the information source. [7]

By frequency:

- Static magnetic field
- Low frequency magnetic field
- Radiofrequency electromagnetic field

Be wavelength:

- Infrared
- Visible
- Ultraviolet

Static magnetic fields are constant fields, which do not change in intensity or direction over time, in contrast to low and high frequency alternating fields. Hence, they have a frequency of 0 Hz. They exert an attracting force on metallic objects containing, for example, iron, nickel or cobalt, and so magnets are commonly used for this purpose. In nature, the geomagnetic field of the earth exerts a force from south to north that allows, for example, the operation of a compass. Much stronger fields are generated by some types of industrial and medical equipment, such as in Medical Resonance Imaging (MRI) devices. [8]

Static electric fields are constant fields, which do not change in intensity or direction over time, in contrast to low and high frequency alternating fields. Hence, static electric fields have a frequency of 0 Hz. They exert a force on charges or charged particles. The strength of a static electric field is expressed in volts per meter (V/m). [9]

Low Frequency (LF) is the abbreviation used for low frequency time-varying electric and magnetic fields, which describes that part of the electromagnetic spectrum comprising the frequency range from 1 Hz to 100 kHz. LF fields have two components: an electric field due to an electric charge, and a related magnetic field. Magnetic fields only occur when an electric current is flowing. The electric component is measured in volts per meter (V/m). The magnetic component is measured in amperes per meter (A/m) and expressed as a flux density in tesla (T) or in some countries in gauss (G). LF is used for power supply. [10]

"Radiofrequency Electromagnetic Fields" (RF EMFs) is the term used to describe the part of the electromagnetic spectrum comprising the frequency range from 100 kHz to 300 GHz. Within this frequency range, the electric and the magnetic fields, which together make up the electromagnetic fields, are interrelated and considered jointly for measurements. RF EMF exposure is usually measured in watts per square meter (W/m2) or watts per kg (W/kg) and used for telecommunications and medical purposes. [11]

Infrared radiation (IR), also known as thermal radiation, is that band in the electromagnetic radiation spectrum with wavelengths above red visible light between 780 nm and 1 mm. IR is categorized as IR-A (780 nm-1.4 µm), IR-B (1.4-3 µm) and IR-C, also known as far-IR (3 µm-1 mm). Common natural sources are solar radiation and fire. Common artificial sources include heating devices, and infrared lamps used and in the home and in infrared saunas for health purposes. [12]

The wavelength range where optical radiation is visible does not have sharp borders. Here, the wavelength band of 380 nm to 780 nm is used. There is an overlap with the UV wavelength range that extends to 400 nm and in the upper range with Infrared. Common natural sources that produce visible radiation are the sun and fire. Common artificial sources include lamps for lighting, projectors, displays, indicator lights, welding arcs and lasers. [13]

Ultraviolet (UV) radiation is the band of non-ionizing radiation that lies next to ionizing radiation in the electromagnetic spectrum. UV radiation is categorized as UVA (400–315 nm), UVB (315–280 nm) and UVC (280–100 nm). The sun is the major source of UV but all of the sun's UVC and much of the UVB are absorbed by the earth's atmosphere so that at the earth's surface the highest proportion of UV is UVA (over 90%). However, exposure to UVB is biologically far more relevant than UVA. Several sources of artificial UV are found in occupational and medical settings. These include mercury vapor lamps, arc-welding equipment, and commercial bactericidal UV lamps and dental polymerizing equipment. Sunbeds used for cosmetic tanning have become a more prevalent source of UV exposure in many countries in the last two decades. [14]

# 3.Legislations

Nowadays all countries in the world regulate work process in factories and productions by official documents with safety norms and legislations. In Czech there is directive 2013/35/EU which prescribes norms for non-optical radiations.

Tab.1 Radiation hazards

| Name | Frequency or Wavelength | Effect | Protection |
|---|---|---|---|
| Static Magnetic Field | 0 Hz | Reducing of blood moving speed in vines, causing of dizziness and nausea | Reduced speed of moving through filed |
| Static Electric Field | 0 Hz | Spark discharges (micro shocks) | |
| Low Frequency | 1 Hz-100 kHz | Tissue burns and cardio-vascular effects | Limiting of interaction human body with LF field to avoid threshold level |
| Radiofrequency Electromagnetic Fields | 300 kHz -300 GHz | Heat, heatstroke and burns | Personal protective equipment and emitter shielding |

Hygienic limits

Tab.2 ALs for exposure to electric fields from 1 Hz to 10 MHz

| Frequency range | Electric field strength Low ALs (E)($Vm^{-1}$) (RMS) | Electric field strength High ALs (E)($Vm^{-1}$) (RMS) |
|---|---|---|
| $1 \leq f < 25$ Hz | $2 \times 10^4$ | $2 \times 10^4$ |
| $25 \leq f < 50$ Hz | $(5 \times 10^5) \div f$ | $2 \times 10^4$ |
| 50 Hz $\leq f <$ 1,64 kHz | $(5 \times 10^5) \div f$ | $(1 \times 10^6) \div f$ |
| $1{,}64 \leq f < 3$ kHz | $(5 \times 10^5) \div f$ | $6{,}1 \times 10^2$ |
| 3 kHz $\leq f \leq$ 10 MHz | $1{,}7 \times 10^2$ | $6{,}1 \times 10^2$ |

Tab.3 ALs for exposure to electric and magnetic fields from 100 kHz to 300 GHz

| Frequency range | Electric field strength ALs (E)($Vm^{-1}$) (RMS) |
|---|---|
| 100 kHz $\leq f <$ 1 MHz | $6{,}1 \times 10^2$ |
| $1 \leq f < 10$ MHz | $(6{,}1 \times 10^8) \div f$ |
| $10 \leq f < 400$ MHz | 61 |
| 400 MHz $\leq f <$ 2 GHz | $3 \times 10^{-3} \times f^{0{,}5}$ |
| $2 \leq f < 6$ GHz | $1{,}4 \times 10^2$ |
| $6 \leq f \leq 300$ GHz | $1{,}4 \times 10^2$ |

# 4. Interaction of EM waves with human body

At the present stage of development, man cannot live without electromagnetic fields, despite the fact that they have a detrimental effect on health. Many gadgets have become an integral part of every person's life, we use the phone all day, heat food in the microwave, watch TV, play on the computer, and so on.

## 4.1 The influence of physical factors on the human body

Every day people are exposed to various adverse environmental influences, this includes exposure to electromagnetic fields.

Sources of natural electromagnetic fields include atmospheric electricity, solar radiation and cosmic rays. Artificial sources include: various lasers, measuring devices, power lines, generators and so on.

During the evolution of life processes on earth, human life has always interacted with the electromagnetic field of the Earth, and later adapted so that any change and action of the fields of the Earth affects the vital factors of man. For example, before a thunderstorm man feels sluggish due to the increased strength of the electric field, the cause of many car accidents are magnetic storms, which are the consequence of solar activity, also adversely affecting the health of many elderly people.

The earth's electromagnetic sphere can be defined by five criteria:

- magnetic and electric fields,
- atmospheric electricity,
- radio radiation,
- artificial sources of fields.

Electrostatic fields can occur when working with easily electrifiable materials such as wool, silk, viscose. In radio engineering, permanent magnetic field sources such as DC electromagnets and sintered magnets are used. For industrial frequencies, sources such as protective equipment, measuring instruments, overhead power lines and substations are used.

Sources of electromagnetic radiation at radio frequencies are primarily powerful radio and television broadcasting stations, antennas, induction and dielectric installations, high frequency devices in medicine and households.

Microwave ovens, televisions and mobile phones are sources of danger in everyday life. A special type of magnetic radiation is laser radiation, which is generated in a laser. [15]

### 4.2 Human exposure to electromagnetic waves

The process of exposure of humans and other biological beings to electromagnetic waves has not been sufficiently studied because the human body is constantly under the influence of the electromagnetic field, which causes the molecules of the human body to be polarized.

As the frequency of the field increases, the properties of living organisms' tissues change dramatically, the energy penetrating the body is repeatedly refracted in the multi-layered structure of the tissue layers. Electromagnetic fields affect the body biologically and thermally (tissue heating).

Heat energy that occurs in tissues increases body temperature, if the thermoregulatory function of the body is unable to remove heat from the body, the excess heat can cause overheating of tissues and organs, the blood supply of which is poorly developed or have poor thermoregulation, eventually leading to disease.

Negative exposure to electromagnetic fields may lead to inhibition of reflexes, lowering of blood pressure, slowing of heart beats, changes in blood composition, clouding of the lens of the eye (cataract).

Intense ultrahigh frequency radiation can lead to total loss of vision, moderate intensity leads to disturbances in carbohydrate and fat metabolism, which is accompanied by high excitability and weight loss.

During operation of laser installations, the following harmful factors may affect the human body: infrared radiation, noise, vibration. Biological effects occur when the human body is exposed to laser radiation. In total, there are primary and secondary effects. Primary changes occur in tissues directly under the influence of radiation (burns, hemorrhages) and secondary (side effects) are caused by various abnormalities in the human body caused by radiation.

The human eye is the most sensitive to the effects of laser radiation. Dangerous exposure of skin to the laser beam may cause burns of various degrees of severity. High intensity laser beams cause damage to various human internal tissues and organs, manifesting as hemorrhages, swellings and blood clotting. [15]

### 4.3.Thermal effect of electromagnetic fields

Overheating of body tissues does not directly depend only on the magnitude of the electromagnetic field energy, but also on the ability of a particular organism to thermoregulate.

If we turn to the materials of the St. Petersburg State Electrotechnical University, experiments carried out with phantoms imitating the body of animals showed that with an increase in the volume of an object, it takes more and more time to heat it to a given temperature using an EMF of a given power. This is explained, firstly, by the fact that more calories are needed to heat a larger volume, and, secondly, by the fact that at the same depth of penetration of EMF energy into the tissue, the fraction of the volume in which absorption occurs will be the greater, the smaller the volume ... For example, if an EMF with a frequency of 300 MHz penetrates to a depth of 2.5 cm (for muscle tissue), this means that in a rat (body diameter 5-6 cm), EMF energy is absorbed in almost the entire body, and in a dog (body diameter 20-25 cm) - only in an insignificant surface of a part of the body.

A more detailed theoretical study of the conditions for heating tissues of the human body and various animals under the action of microwaves was carried out. The time required for an increase in body temperature by 5 ° (ΔT = 5 °) was calculated from the equation:

$$t = \frac{GC_b\Delta T}{E + M - S_b\alpha_{ab}(\theta_{ab} + \Delta T)}, \qquad (5)$$

where G - body mass, $C_b$ - specific heat capacity, M - heat due to metabolism, E-heat due to microwave irradiation, $S_b$- body surface, αab - heat transfer coefficient air - body, $\theta_{ab}$ - initial air - body temperature difference.

As a result, the researchers concluded that at very large values of t, corresponding to a low radiation intensity, there is practically no difference in the heating rate of animals of different sizes, but at high intensities (t is small) the body of small animals heats up faster.

The results of most studies of the dependence of heat generation in animal tissues on the intensity and time of exposure to EMF, as well as the nature of temperature distribution in tissues, were contradictory: in some cases, more significant heating was noted in deep tissues compared to superficial ones, in others - the opposite temperature distribution, in others - the presence of both positive and negative temperature gradients depending on the conditions of exposure to EMF. The main reasons for these discrepancies can be considered the imperfection of the dosing of the absorbed power and the incomparability of a number of experimental conditions.

Attempts have been made to theoretically estimate the amount of heat released at a given distance from the irradiated surface and calculate the corresponding temperature rise. However, a comparison of the calculated and experimental data showed an approximate agreement only for short irradiation times.

An experimental assessment of the threshold EMF intensities for the thermal effect was carried out in various frequency ranges for general and local exposure to EMF on humans and animals. The limit of the thermal effect was determined by the minimum increase in body or tissue temperature, not exceeding its normal fluctuations in the body. The minimum heat sensation was also used as a sign of the appearance of a heat effect in humans. It was found that the relationship between the sensation of heat and the power of the EMF absorbed in the tissues (in the range of 20-200 MHz) is expressed by the ratio:

$$H = \log P - a \log P_0, \qquad (6)$$

where H is the heat sensation, estimated according to a 4-point system (barely perceptible heat, moderate heat, intense heating, barely tolerated heating), $Po$-absorbed power at which barely noticeable heat is felt, P-given absorbed power, and is constant, not frequency dependent (although $Po$ varies with frequency).

From the results of the experiment, it follows that the threshold EMF intensities decrease with increasing frequency. This is understandable, since the absorption coefficient of electromagnetic energy is proportional to the frequency and the magnitude of the electrical parameters σ and ε, which in turn change with frequency.

In conclusion, it should be noted that in works devoted to the thermal effect of EMF, the possibility of selective heating of microparticles in biological media, which is not accompanied by significant heating of their environment, has been repeatedly discussed. However, theoretical analysis showed that such selective heating is possible only if the particles are large enough — at least 1 mm in diameter. Therefore, there is no reason to count on selective heating of microparticles (cells, bacteria) in the absence of significant heating of the medium in which they are suspended. [16]

### 4.4 Non-thermal effect of electromagnetic fields

Electromagnetic fields (EMF) are generally believed to have no relevant non-thermal effects on cells, tissues, and living organisms. Only EMF with an excessive strength of $>1.000$ kV/m exhibits non-thermal membrane effects such as electroporation or bactericidal microwave exposure. Recently, non-thermal effects have been clinically exploited with the tumor-treating field method, which applies an EMF at radio frequencies (RF) of 100–300 kHz with a moderate strength of 100–150 V/m. The scientific community considers the risk of such moderate-strength

RF-EMF to be negligible, at least with respect to potential hazards caused by power lines or mobile phones. [17]

# 5. Measurements

Before the starting measure the electric field, it is necessary to choose suitable equipment because each antenna has own frequency range which can be measured with its help. For my research part I need to measure the several ranges: from 9kHz to 30 MHz, from 30 MHz to 200 MHz, from 200 MHz to 1 GHz, from 1 GHz to 6 GHz. Also, it requires spectrum analyzer.

There is the list of needed equipment:

Antennas:

HFH2-Z2E (from 9 kHz to 30 MHz): Antenna has loop shape, frequency range 8,3 kHz to 30MHz, low filed strength (<-70 [dBμV/m]), nominal impedance 50 Ω, N female connector, loop diameter 600mm and weight 3kg.

Pic. 7 HFH2-Z2E [18]

BC-01 (from 30 MHz to 200 MHz): Antenna has bicanonical shape and easily works with analyzers and receivers. It has nominal impedance 50 Ω, gain -15 +2 dB, antenna factor 8 to 14 dB/m, maximal input factor 100 Watts, N female connector, dimension 65 x 65 x 137 cm and weight 1,8 kg.

Pic. 8 BC-01[19]

LP-02 (from 200 MHz to 1 GHz): Antenna has log-periodic shape, frequency range 200 MHz to 3 GHz, nominal impedance 50 Ω, gain 6 dB, antenna factor 13 to 36 dB/m, maximal input factor 100 Watts up to1 GHz 50 Watts up to 3 GHz, N female connector, dimension 700 x 100 x 860 mm and weight 1,1 kg.

Pic. 9 LP-02 [20]

BBHA 9120E (from 1 GHz to 6 GHz): Shape of antenna is horn. Frequency range 500 MHz to 6 GHz, usable, frequency 500 MHz to 8 GHz, nominal impedance 50 Ω, gain 6 dB to 18 dB, antenna factor 19 to 29 dB/m, maximal input factor 1400, N female connector, dimension 424 x 605 (820) x 314 mm and weight 4,1 kg.

Pic.10 BBHA 9120E [21]

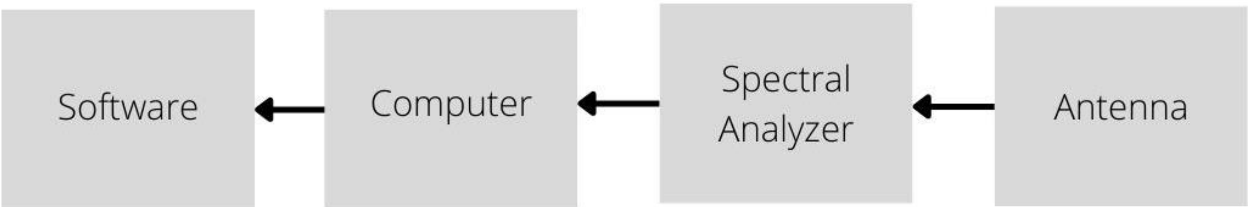
Spectrum analyzers:

ESR 7: frequency range from 10 Hz to 7 GHz.

## 5.1 Methodology of measurements.

For performing the measurements, I chose three locations such as EMC chamber, balcony and library of department of electronics and information technologies. The reason why I took these places is because there are many different sources of EM waves on the roof of the faculty of economy and balcony is good located to make measurements properly, in the library of the department I can make an assessment based on measurements, whether the working conditions of the university staff comply with the norms and regulations. As for EMC chamber, it provides to make a graphs that will be too close to ideal. I decided to perform measurement for each antenna (BC-01, LP-02, BBHA 9120E). I performed measurement with vertical and horizontal polarization of antenna and for more azimuths for precise results. Max-hold function was used for measurement at each location.


Pic. 11, 12 Performing of measurements in library




Pic.13 Schematic diagram of measurements

## 5.2 Results of measurements

Fig.1 Result for 9 kHz-30 MHz, 0 degree

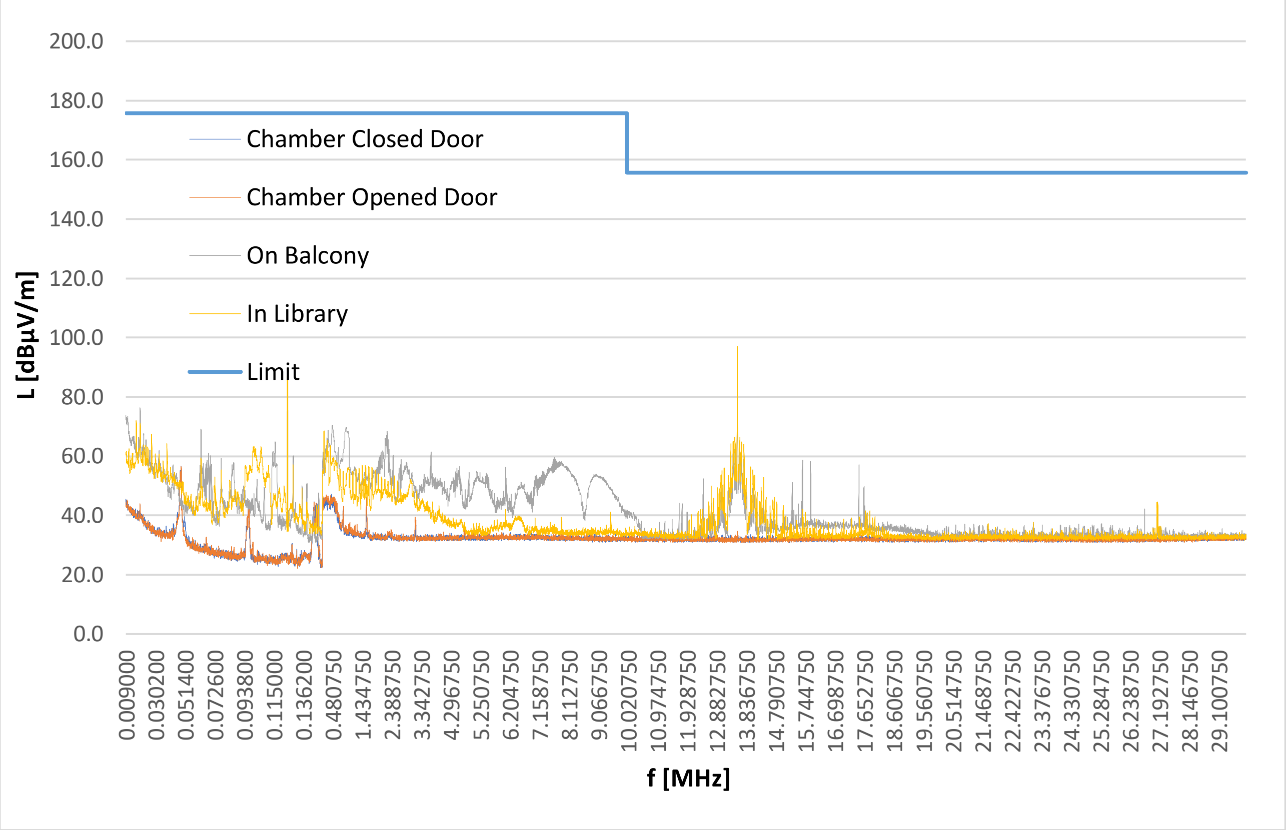
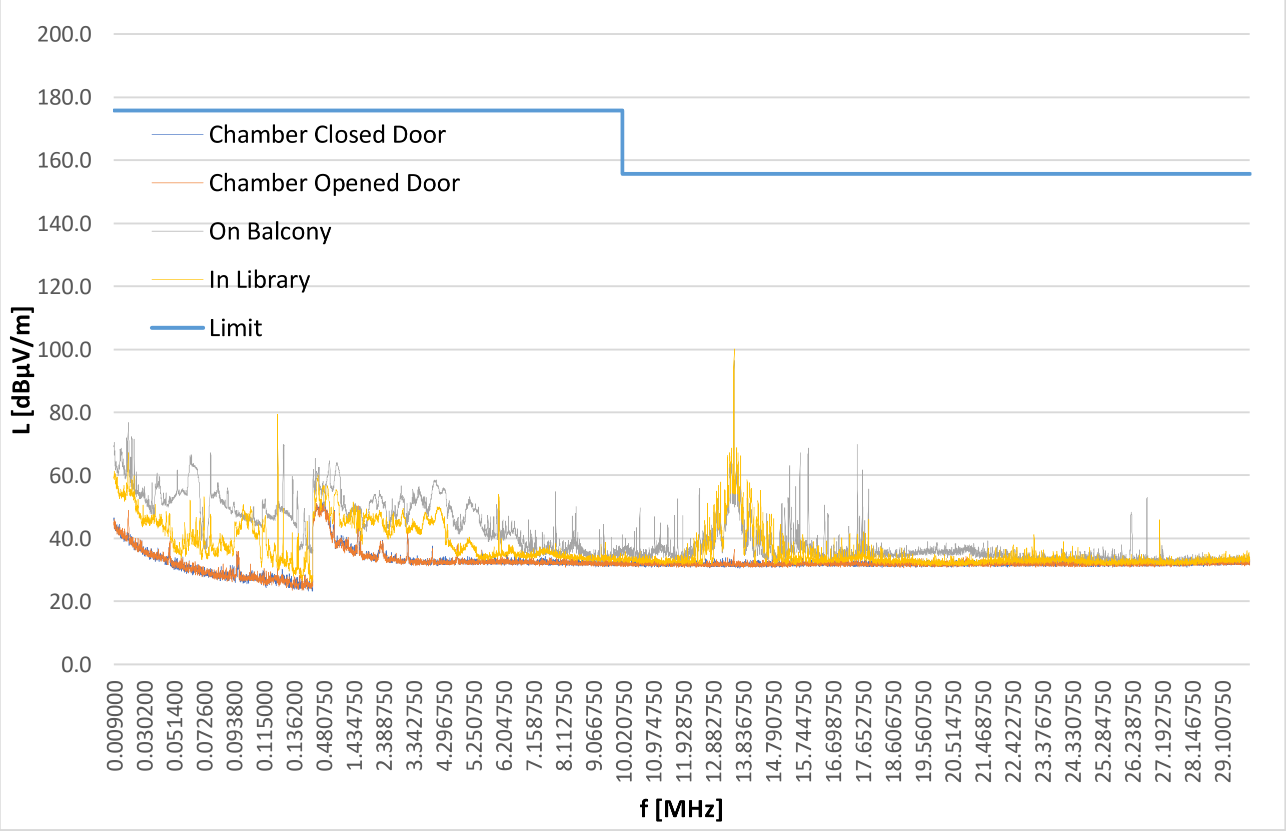



Fig. 2 Result for 9 kHz-30 MHz, 90 degree



For this frequency range there are many services such as radionavigation, meteorological aids, fixed, standard frequency and time signal, maritime mobile, broadcasting, aeronautical radionavigation, maritime radionavigation, amateur, land mobile, radiolocation, space research, amateur satellite, radio astronomy. At frequency from 9 kHz to 30 MHz values of all curves are below the limitation of hygienic norms and smaller twice or more, than values of limiting curve, also we can notice that the highest peak at frequency around 13,56 MHz on both pictures equals 95,6 dBμV/m (0 degree) and 98,6 dBμV/m (90 degree), system RFID (JIS card) works at these values, if we take a look at Radio Frequency Allocation Chart, it is obvious that peaks are related to broadcasting. One more interesting thing is curves of opened and closed door EMC chamber are repeat each other.

Fig.3 Result for 30-200 MHz, horizontal

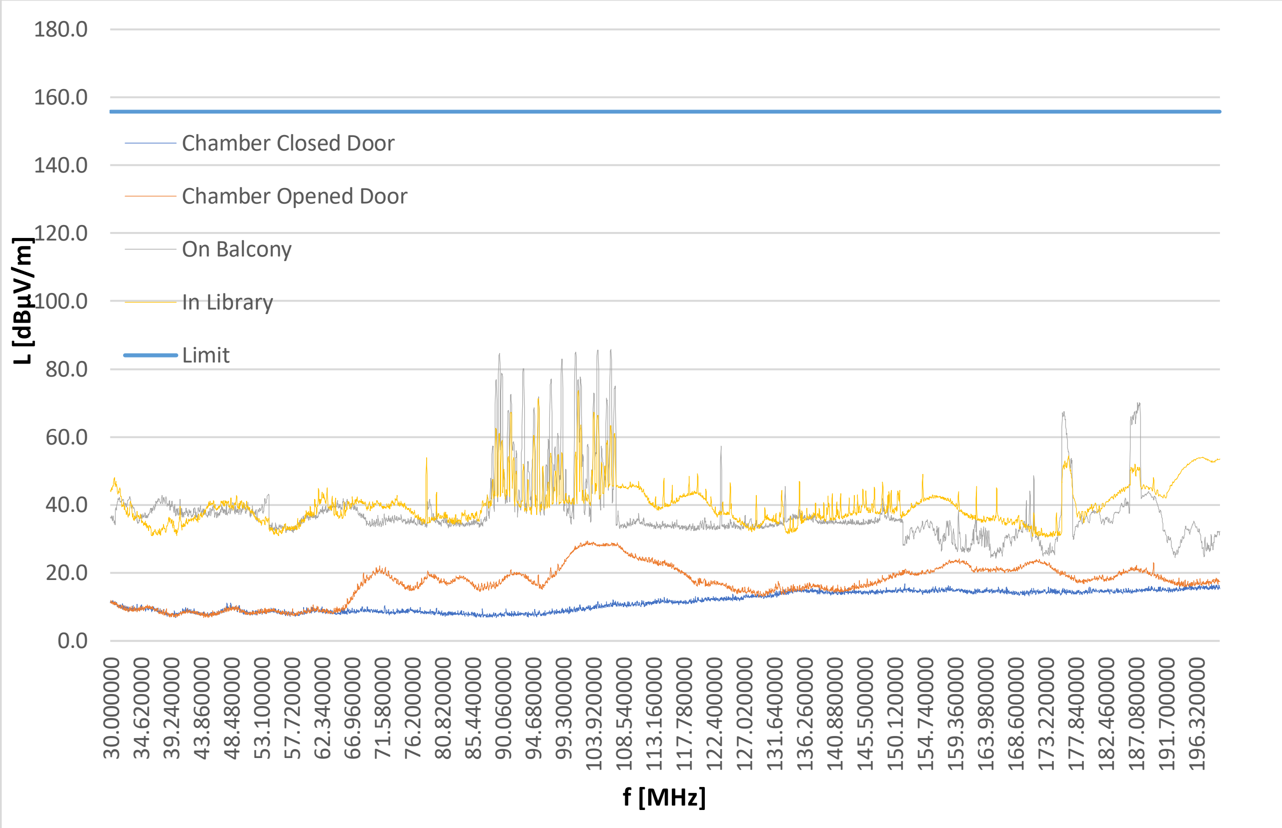
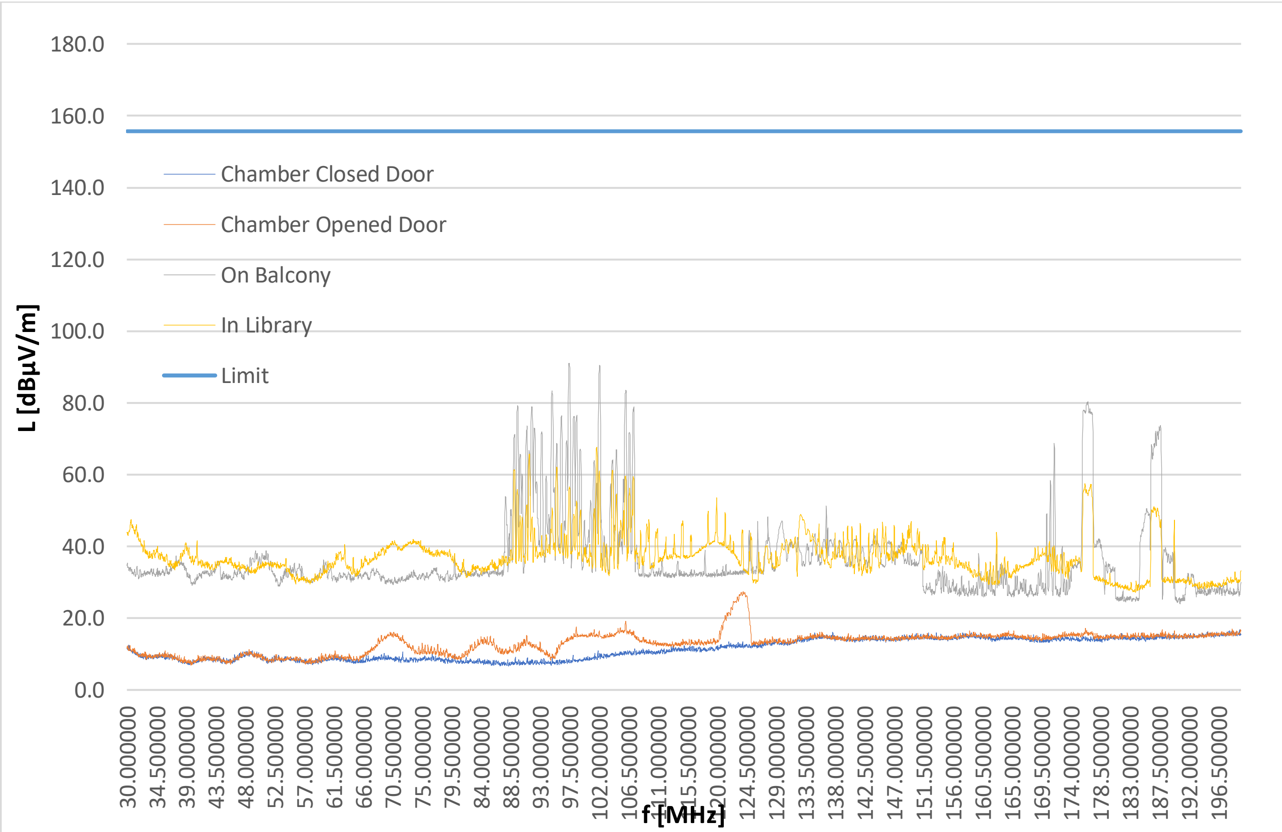



Fig.4 Result for 30-200 MHz, vertical




In the following frequency range there are many services such as mobile and mobile-satellite, radio astronomy, space research, fixed, radiolocation, land mobile, amateur and amateur-satellite, aeronautical radionavigation and mobile, meteorological satellite and aids, space operation, maritime mobile and maritime mobile-satellite, broadcasting. The first thing that catches eyes on both pictures is sharp peaks of curves “on balcony” and “in library” at frequency range from 88,02 to 109,2 MHz, according to the Radio Frequency Allocation Chart we can conclude that it is a broadcasting service of FM radio, also easily visible two peaks of curves “on balcony” at frequencies 175,86 MHz and 186,9 MHz which demonstrate broadcasting of television. As for lines of opened and closed EMC chamber they are not the same at whole range because from 65 MHz to 126,6 MHz chart of “chamber opened door” shows activity which can be defined by Radio Frequency Allocation Chart, and it is mobile service and broadcasting of radio and television. Of course, values of all curves are below the limitation line.

Fig.5 Result for 200 MHz-1 GHz, horizontal

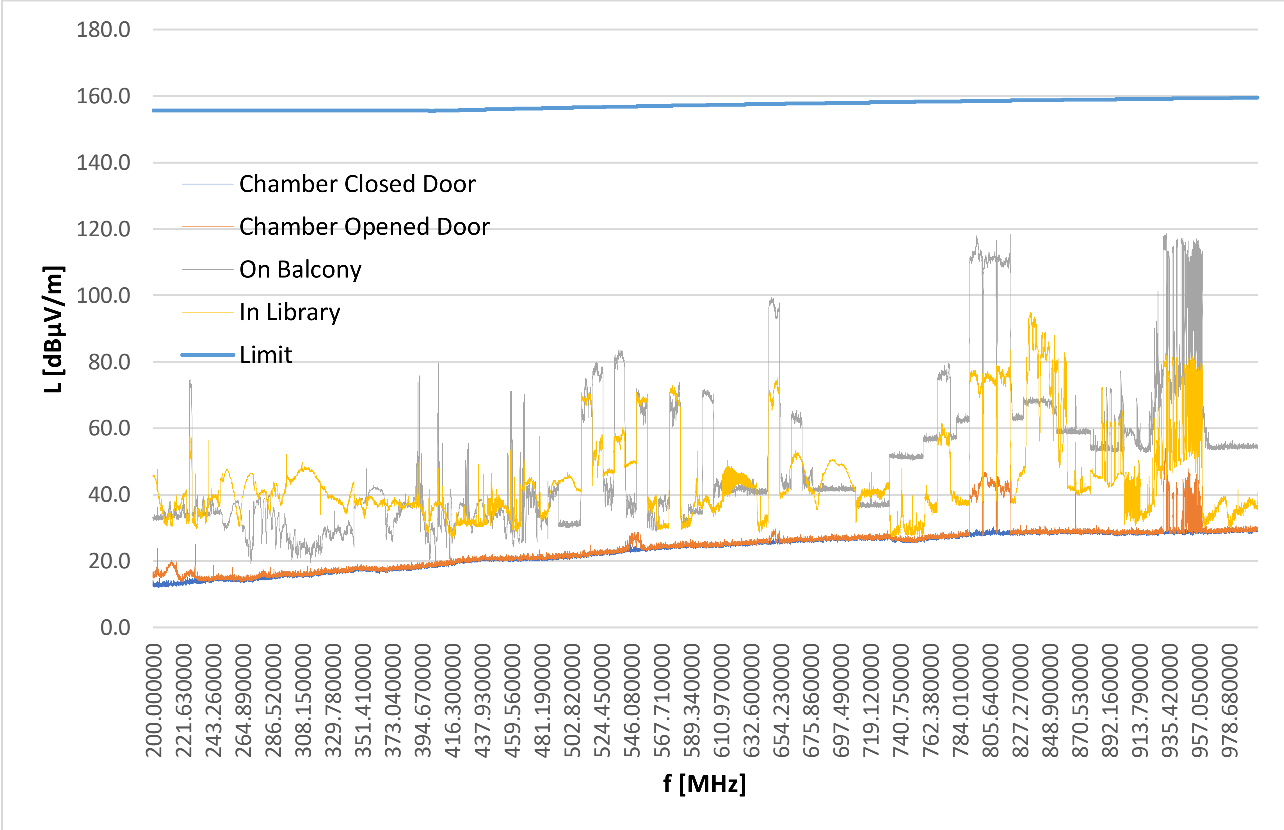
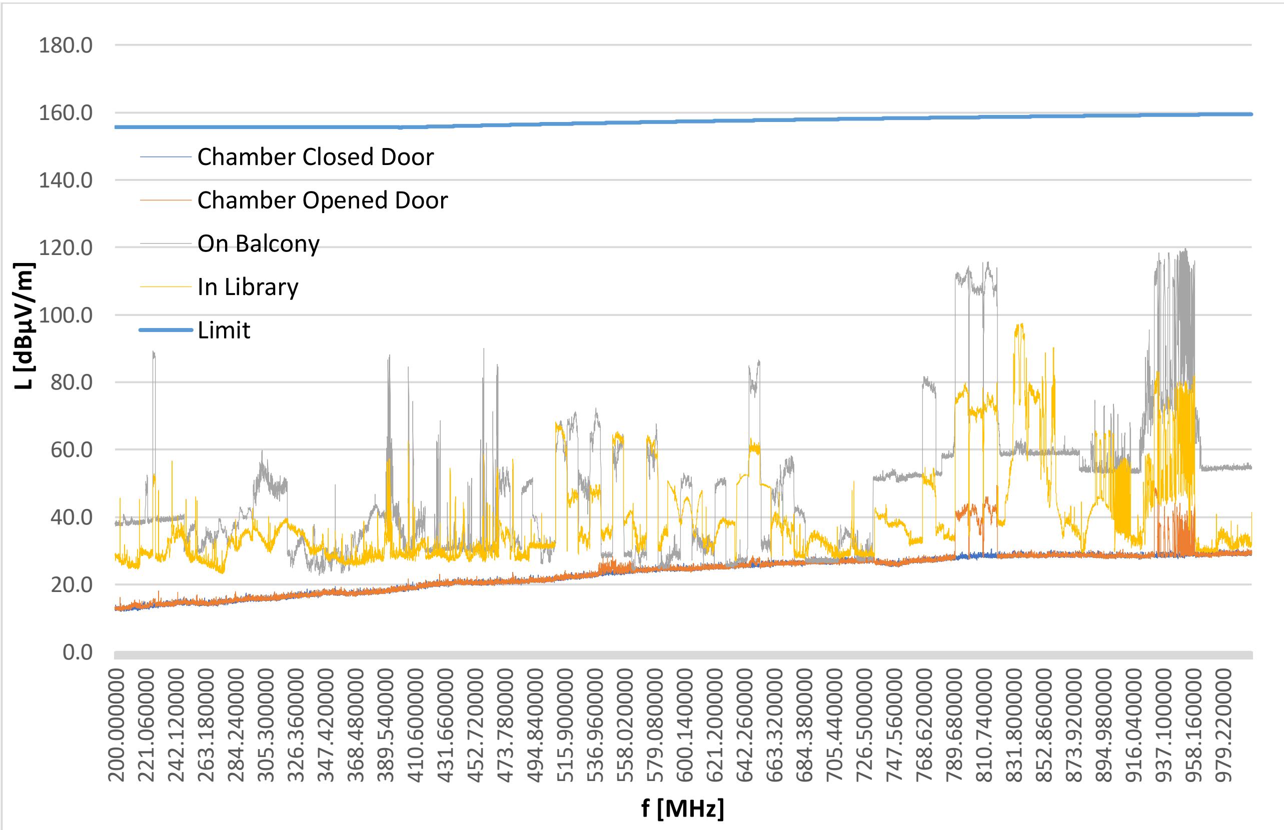



Fig.6 Result for 200 MHz-1 GHz, vertical




The current frequency range is characterized by services such as broadcasting, land mobile, mobile, aeronautical radionavigation and mobile, mobile satellite, standard frequency and time signal-satellite, space research and operations, meteorological aids and satellite, radio astronomy, radiolocation, amateur satellite. The plots of 200 MHz-1 GHz for horizontal and vertical have many sharp peaks of lines "on balcony" and "in library", fat area of curves from 920 MHz to 970 MHz with different electric field strength for locations maintain a fixed and radiolocation services, high points of lines at frequencies 393,05 MHz, 406,58 MHz, 459,41MHz, 469,4 MHz demonstrates mobile and fixed, mobile satellite, land mobile, meteorological satellite and fixed mobile, respectively. The curves of "chamber opened door" and "chamber closed door" are almost the same, only at frequency from 801,14 MHz to 833,84 MHz "chamber closed door" has jump with repeating of "on balcony" and "in library" lines but with less electric field strength. To summarize analysis of plots we can say that values of charts are under limit.

Fig.7 Result for 1-6 GHz, horizontal

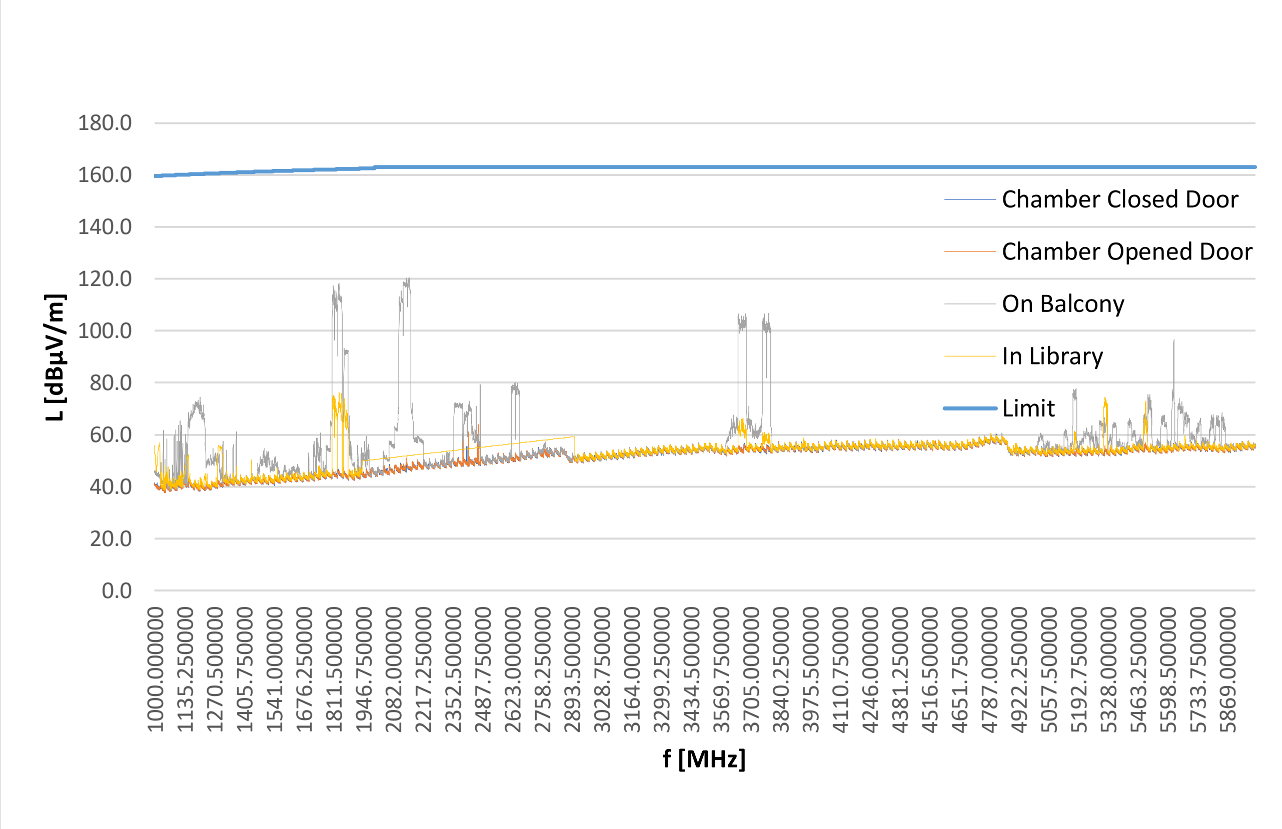
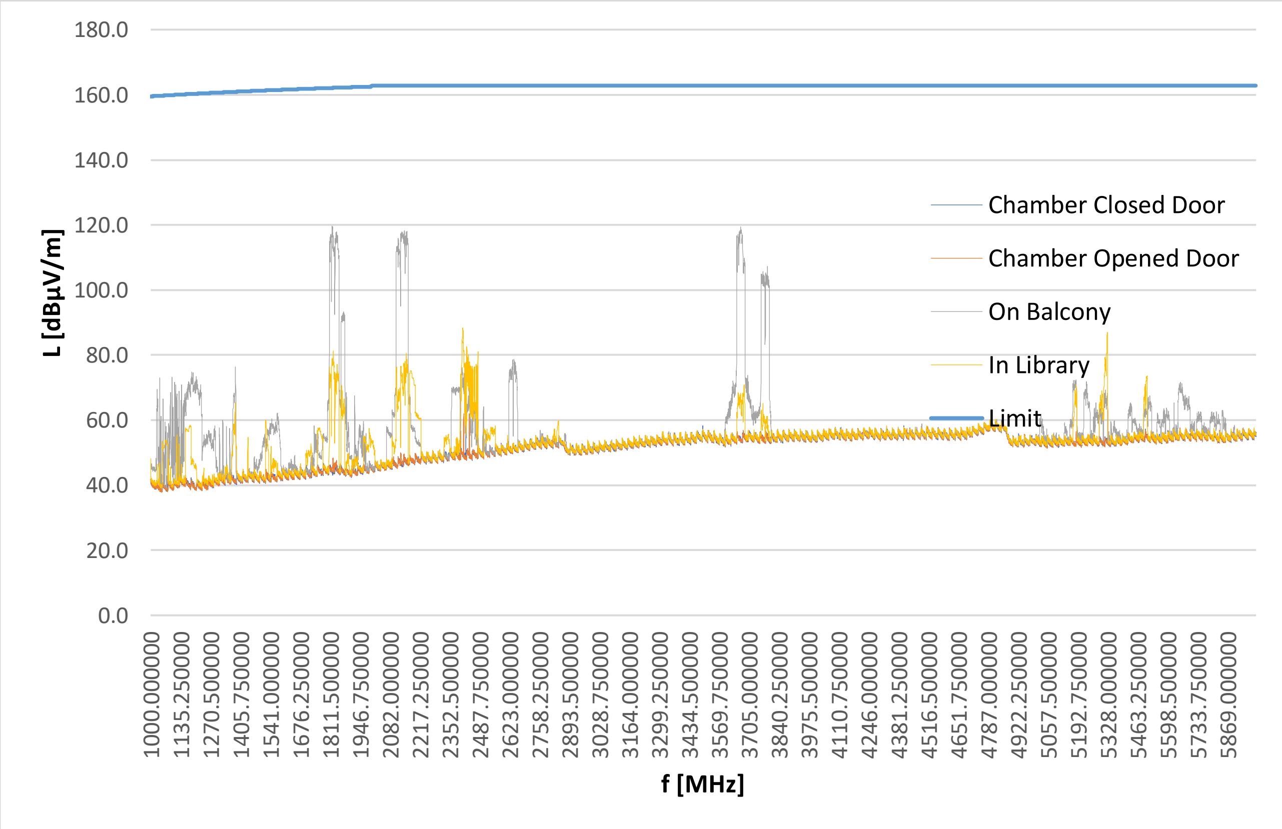



Fig.8 Result for 1-6gGHz, vertical



For this frequency range, services are used such as aeronautical mobile, radionavigation and mobile-satellite, radionavigation-satellite, space research, earth exploration-satellite, radiolocation, amateur, mobile and mobile-satellite, fixed and fixed satellite, radio astronomy, space operation, broadcasting-satellite, broadcasting, radiodetermination-satellite, meteorological aids and satellite. As we can see that all curves of both diagrams are on the same level including peaks of lines "on balcony" and "in library". From the beginning of the frequency range till 1630,25 MHz there are moderate fluctuations of chart that characterize radionavigation-satellite, fixed and mobile service, and mobile satellite actions, also it is clearly visible few sharp peaks at 1852 MHz, 2129 MHz, 2477,75 MHz, 3680,5 MHz, 3799 MHz which demonstrates work of mobile and fixed services, and radiolocation. All measured values are within limits.

# 6. Conclusion

To summarize my thesis, I would like to say that all the objectives have been achieved, in the course of the work I have covered all the aspects necessary to make sense, including the first part, in which I described Maxwell's equations, also during the work I have touched and made clear such topics as: electromagnetic radiation and its types, the effects of electromagnetic fields on humans and the two types of effects (thermal and non-thermal).

Successful measurements were also carried out in accordance with the directive 2013/35/EU, which helped to conclude that the chosen measurement equipment was perfectly suitable. By analyzing the results obtained from the measurements, it can be concluded that the strength of the electromagnetic fields at the selected locations fully complies with the regulations and laws of the European Union.

In my opinion, the topic has been most fully covered and all tasks have been sufficiently analyzed and proved in the course of the work.

## Bibliographic Citations


[1] Online Mephi. Magnetic field of a straight conductor with current. [online], URL: https://online.mephi.ru/courses/physics/electricity/external/images/000281.jpg

[2] SolverBook. Lenz's Law. [online], URL: http://ru.solverbook.com/my_images/pic5013.jpg

[3] Physicsleti. Gauss Theorem. [online], URL: http://physicsleti.ru/files/fiz/assets/images/1_4/image008.gif

[4] SolverBook. Maxwell's equations in integral form. [online], URL: http://ru.solverbook.com/my_images/pic1742.png

[5] Katrin Lindbäck. Hydrology and Bed Topography of the Greenland Ice Sheet: Last known surroundings. In Uppsala, 2015. Doctoral work (Ph.D.), University of Uppsala. Faculty of Science and Technology.

[6] Principles of Structural Chemistry. Electromagnetic spectrum. [online], URL: https://sites.google.com/a/coe.edu/principles-of-structural-chemistry/_/rsrc/1468739013723/relationship-between-light-and-matter/electromagnetic-spectrum/EMSpectrumcolor.jpg

[7] ICNIRP. Frequencies. [online], URL: https://www.icnirp.org/en/frequencies/index.html

[8] ICNIRP. Static Magnetic Fields. [online], URL: https://www.icnirp.org/en/frequencies/static-magnetic-fields-0-hz/index.html

[9] ICNIRP. Static Electric Fields. [online], URL: https://www.icnirp.org/en/frequencies/static-electric-fields-0-hz/index.html

[10] ICNIRP. Low Frequency. [online], URL: https://www.icnirp.org/en/frequencies/low-frequency/index.html

[11] ICNIRP. RF EMFS. [online], URL: https://www.icnirp.org/en/frequencies/radiofrequency/index.html

[12] ICNIRP. Infrared Radiation. [online], URL: https://www.icnirp.org/en/frequencies/infrared/index.html

[13] ICNIRP. Visible Radiation. [online], URL: https://www.icnirp.org/en/frequencies/visible/index.html

[14] ICNIRP. Ultraviolet. [online], URL: https://www.icnirp.org/en/frequencies/uv/index.html

[15] Gaizetdinova A.M., Gaisina G.A. Electromagnetic Field and Its Impact on Human Health. Modern Problems of Science and Education. Surgery. 2018. № 3-1. 155-157. ISSN 2070-7428.

[16] Studfile. Protection against electromagnetic radiation and fields. [online], URL: https://studfile.net/preview/940746/

[17] Peter Wust, Benedikt Kortüm, Ulf Strauss, Jacek Nadobny, Sebastian Zschaeck, Marcus Beck, Ulrike Stein, Pirus Ghadjar. Non-thermal effects of radiofrequency electromagnetic fields. Scientific report. Nature Research. 2020. 8 pages.

[18] Rohde&Schwarz. R&S®HFH2-Z2E active loop antenna. [online], URL: https://cdn.rohde-schwarz.com/image/products/aerospace-defense-security/antenna/emc-antennas/hfh2-z2e/hfh2-z2e-front-view-rohde-schwarz_200_1440_1280_720_7.jpg

[19] Narda. BC-01 – Biconical antenna 30 – 200 MHz. [online], URL: https://www.narda-sts.it/wp-content/uploads/2019/07/BC-01@2x.png

[20] Narda. LP-02 – Log Periodic Antenna 200 MHz – 3 GHz. [online], URL: https://www.narda-sts.it/wp-content/uploads/2020/12/lp-02-no-sfondo-218x300@2x.png

[21] Schwarzbeck. BBHA 9120 E - Double Ridged Broadband Horn Antenna. [online], URL: http://www.schwarzbeck.de/images/ANT/Horn/9120e/thumbs/Horn%20Antenna%20BBHA%20 9120%20E.jpg

# Picture list

# List of tables