The electromagnetic field and people

On physics, biology, medicine, standards, and the 5G network

Ministry
of Digital Affairs

We are pleased to present this publication, which discusses, in a comprehensible manner, the most important issues related to the radio-frequency electromagnetic field. It is those fields that allow us to enjoy radio and television broadcasts and to use mobile phones. Thus, it is the basis for a trouble-free and fast flow of information, which is the foundation of our civilization nowadays.

This publication is divided into four sections. The first three sections answer the most frequently asked questions about electromagnetic waves. What are they? What are their effects on the human body? How are they measured and what regulations apply to them? The fourth section briefly explains the relationship between the electromagnetic field and telecommunication, and what the next generation of cellular networks, i.e. 5G, is.

We are sure that this publication will help everyone interested in this topic to understand what the electromagnetic field is and how we can use it for the good of Poland.

We hope you will find it interesting!

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I. Physics

Introduction

- The electromagnetic field is one of the fundamental elements of the natural world. It occursnear all electrically charged particles, moving charges, and permanent magnets.
- In the electromagnetic field, its excitations – electromagnetic waves – move. These waves carry energy.
- According to modern physics, such a wave can also be considered a flow of particles – photons.

  - Electromagnetic waves can differ in length – i.e. the distance between successive crests – which determines their frequency – i.e. a measure of how many times in a fixed unit of time, usually 1 second, the crest of a wave passes through a given point. Electromagnetic waves of different lengths/frequencies also have different energy. The longer the wave (and therefore the lower the frequency), the lower the energy of one photon.
  - The division into ionizing and non-ionizing radiation is important. It is related to the photon's ability to ionize, in other words to induce a reaction that causes the conversion of an electrically neutral atom or a chemical particle into a charged molecule i.e. an ion. In practice, this means that ionizing radiation can cause chemical reactions, thus influencing the molecules in the cells of living organisms, e.g. DNA.
  - Electromagnetic waves in the radio and microwave frequency ranges are non-ionizing. Their most important applications include: AM, FM, and DAB radio, digital terrestrial television, mobile telephony, Wi-Fi, Bluetooth, and radar. In medicine, however, ionizing radiation is more commonly used, e.g. in X-ray examinations or cancer radiotherapy.

- The basic quantities that enable a quantitative description of the electromagnetic field are electric field strength E, magnetic field strength H, and power density S of the electromagnetic wave.
- Waves traveling ("propagating") in a space interact in different ways with objects found in the space. This leads multiple reflections of the wave, refraction, refraction, interference, attenuation and scattering.
- As a result of these phenomena, the field strength at a given point, especially in an urban environment, can be difficult to predict and can change constantly, even with a fixed source (antenna) position.

    - There are numerous natural sources of the electromagnetic field.
    - Earth is the source of its own magnetic field, which is created in the planet's liquid core. In the atmosphere, various types of magnetic and electric fields are generated, the result of which in natural electric discharges (lightning).
    - Every body with a temperature exceeding the temperature of absolute zero (or, in practice, every body in the Universe) is also a source of so-called thermal radiation. In the case bodies with temperature equal to room temperature, thermal radiation is in the infrared range.

- For almost 150 years, humanity has been using, to an ever greater extent, devices and installations that are sources of the electromagnetic field.
- In Poland, the first radio broadcasting stations were built in the 1920's. In 1923, a broadcasting center was established near Warsaw and, in 1927, broadcasting stations were built in Cracow, Poznań, and Katowice.
- Every electrical device – such as a TV set, a hairdryer, a refrigerator, an induction hob, a laptop, or a mobile phone – is a source of the electromagnetic field.

    - The basic unit of organization of the mobile network is a "cell": an area covered by one base station.
    - In a base station there are sector antennas that are used for communication with the users, and radio link antennas for communication with other base stations or the base station controller.
    - A terminal (i.e. any device that uses a cellular network, e.g. a mobile phone) is also a transmitter whose operating power increases with its distance from the base station. The power of the terminal is thus the greatest at the cell boundary and decreases as the user approaches the base station antenna.

I.1
Electromagnetic field, electromagnetic waves

Rafał Pawlak

The Universe, according to the most likely evolution model referred to as the "Big Bang," emerged about 14 billion years ago. From the very dense and hot singularity emerged space, time, matter, energy, and their mutual interactions. In the Universe expanding over the billions of years that followed, electromagnetic phenomena play a great role. They belong to numerous, extremely important and core processes, which from the very beginning formed and continue to shape the Earth's natural electromagnetic environment, being its integral part. The energy accompanying electromagnetic phenomena, which is one of the oldest forms of energy in the Universe, was one of many factors that influenced the evolution of our planet and the life on it.

The electromagnetic field undoubtedly accompanies humans not only "always", but also everywhere, in every part of their lives. Humans, like our entire planet, are located in the vicinity of a giant source of electromagnetic waves of a very wide spectrum, which is the Sun. The human body not only uses the electromagnetic field and has acquired, through evolution, resistance to some of its forms, but also has become a source of the electromagnetic field – and in a fairly wide frequency range. Furthermore, for over 100 years, the mankind has been generating artificial sources of the electromagnetic field.

Four interactions

The electromagnetic field is one of the four interactions naturally observed in nature that are of fundamental importance, the so-called fundamental interactions, which cannot be reduced to other, more basic interactions. Those interactions are:

- the gravitational interaction (classically, it is a universal gravity force associated with attraction between molecules with mass);
- the weak nuclear interaction (responsible for some forms of decay of atom nuclei and elementary molecules);
- the strong nuclear interaction (occurs in atom nuclei, mediating between the constituent elementary molecules); and
- the electromagnetic interaction (occurs between charged molecules).

There are even some similarities between the electromagnetic interactions and the gravitational interactions. For example, the range of both interactions is infinitive, as opposed to the two interactions that are rightly called “nuclear,” the range of which is limited in practice to the nearest surroundings of molecules, such as protons and neutrons. However, each interaction is different, and the gravitational interaction is, for example, incomparably weaker than the electromagnetic interaction: for example, the electromagnetic force exerted by a tiny magnet on a small metal object can easily overcome the gravitational force generated by the entire globe.

Radiation or field?

The term "radiation" is a purely technical term used to describe various phenomena associated with energy transmission in the form of waves or particles in space or in another medium. Thus, there is not only electromagnetic radiation (including light, i.e. "visible" radiation), but also e.g. sound and thermal radiation. For some people, "radiation" is associated unambiguously with nuclear energy and fears associated with risks it may entail – but this is only an unfortunate association. The heat that we feel near a radiator is, after all, also a form of radiation, which is completely harmless, and even necessary for life.

Usually the physical term **"field"** means **static fields**: **electric and magnetic** (e.g. an electrostatic field that is present in the vicinity of a sweater that has been rubbed several times and that raises hair put close to it) – and a variable **electromagnetic field**. In the most general sense, the term **"electromagnetic radiation"** could be used to call all forms of time-variable electromagnetic field – i.e. situations where the field consists of migrating **waves**. However, it is often assumed that the word "radiation" covers only those waves whose frequency exceeds 300 GHz (see the infographics on page 38). According to this definition, radio waves and microwaves should not be called "radio radiation" or "microwave radiation," although this is sometimes done, which unfortunately raises misleading negative associations with harmful ionizing radiation[1] or with radioactivity related to nuclear phenomena. Consequently, through unjustified associations with e.g. the tragic events that took place in Hiroshima, Nagasaki, Chernobyl, and Fukushima, a sense of threat can arise. Generally, one should keep in mind that the word "radiation" has no connection to safety or health effects – it is simply a technical term that describes a time-variable electromagnetic field.

1 See: http://ptze.pl/elektrofakty/?article=elektrosmog-w-pogoni-za-sensacyjnymi-naglowkami

In order to properly understand the issues related to the electromagnetic field as a physical phenomenon, one should first look at what the electromagnetic field actually is.

Static electric field

The electric field is a certain energy state of space that is associated with the existence of electric charges which constitute its source. There are positive charges and negative charges. An electric charge is a discrete quantity or, in other words, it is quantized. In practice, this means that there is a certain minimum "unit" of charge (the so-called "elementary charge"), which is $1.6 \cdot 10^{-19}$ C (Coulomb), so the charge accumulated by a body must be an integer multiple of the minimum charge "unit" of charge.

The electric field is quantified by a measurable value, which is called electric field strength E and is expressed in the [V/m] (volts per meter) unit. An image of the electric field, for a better representation and visualization of the phenomenon itself, can be represented graphically by means of the so-called field force lines. The electric field force lines around a single point source charge are straight lines, directed toward a negative charge (they "enter" the negative charge) or from a positive charge (they "exit" from the positive charge) and, importantly, they cannot intersect. They can be determined experimentally, using e.g. hair pieces that get aligned in the direction of the electric field vector E.

The presence of electrostatic interactions in nature was known as equally as in antiquity. Electrostatics was first described in the 6th century BC by the Greek philosopher Thales of Miletus. He noticed that amber, when rubbed with a piece of cloth, starts to attract some small and light objects. In modern times, in the late 16th century, the first research and experiments connected with the phenomena of electric charging of materials and magnetism was started by William Gilbert – the personal physician of Queen Elizabeth I. The Italian mathematician, physicist, and philosopher Nicolo Cabeo, on the basis of his observations, concluded in 1629 that electrically charged bodies can attract

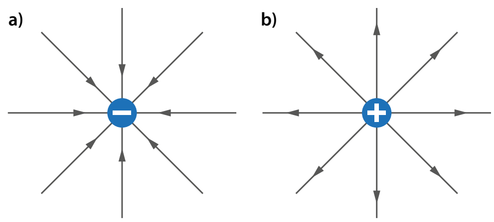


Fig. 1a, b. Electric field force lines around a single negative (a) and positive (b) point source charge.
Author: Paweł Woźniak

bodies that are not electrically charged, while two electrically charged bodies can repel each other. In 1733, the French chemist and physicist Charles François de Cisternay Du Fay introduced a distinction between positive electricity (then referred to as "glass" electricity) and negative electricity (then referred to as "resin" electricity). The American scientist Benjamin Franklin studied atmospheric electricity (in 1752, he built the first lightning rod), suggested that one should distinguish between positive electric charges and negative electric charges, and stated that bodies with like electric charges (e.g. two positive electric charges or two negative electric charges) repel each other, and bodies with opposite electric charges (e.g. one positive charge and one negative charge) attract each other. A breakthrough discovery was made by the French physicist Charles Augustin de Coulomb, who proved Franklin's assumption that like charges repel each other and opposite ones attract each other, and formulated in 1785 a law describing the force of interaction of charges, nowadays called the Coulomb law.

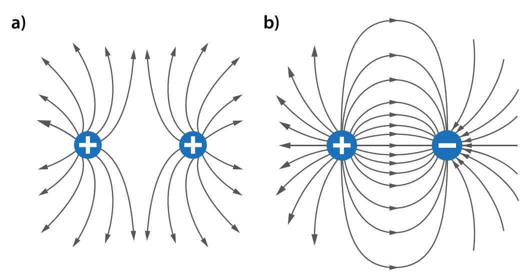


Fig. 2a, b. Electric field force lines around like charges (a) and unlike charges (b).
Author: Paweł Woźniak

Static magnetic field

A magnetic field is a certain energetic state of space induced either by moving electric charges or by certain materials, which are so-called permanent magnets. In the former case, the source of the magnetic field is direct current circuits – a "surrounding" magnetic field is always generated around the wire in which the electric current flows. In the latter case, there is the phenomenon of systematic ordering of the structure of atoms, each of which behaves like a tiny magnet, which results from the property of electrons named "magnetic moment": there is no simple equivalent of an electric charge in the case of magnetism.

The magnetic field is described quantitatively by a measurable quantity, which is called the magnetic field strength H and is expressed in the [A/m] (ampere per meter) unit. The magnetic field is also frequently characterized by the value of magnetic induction B expressed in the [T] (tesla) unit. An image of the magnetic field, for a better representation and visualization of the phenomenon itself, can be represented graphically, in the same way as in the case of the electric field, by means of the so-called field force lines. Magnetic field force lines are closed lines, have no beginning and no end, and have a specific sense. They can be determined experimentally using iron filings that align themselves with the direction of the magnetic induction vector B.

Everyone knows that every permanent magnet has two poles, which traditionally are called the north pole (N) and the south pole (S). The force lines of the magnetic field of such a magnet "exit" from the north pole (N), make a turn, and "enter" into the south pole (S), thus forming a closed loop. Inside the magnet they run from the south pole (S) to the north pole (N).

The phenomenon of generation of the magnetic field by electric current flowing through a conductor was discovered in 1820 by Hans Christian Ørsted, a Danish physicist and chemist. During one of his experiments, he noticed that near a conductor in which electric current is flowing, the needle of the compass is tilted and that the direction of such tilting depends on the current flow direction.

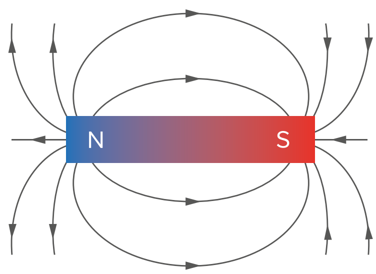


Fig. 3. Magnetic field force lines around a bar permanent magnet. Author: Paweł Woźniak

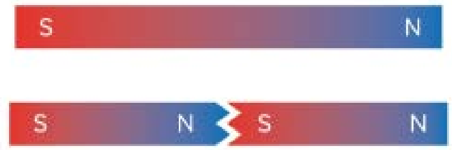


Fig. 4. Division of a bar magnet. Author: Paweł Woźniak

French physicists, Jean-Baptiste Biot and Felix Savart, continued research on magnetism and in 1820 formulated a law that makes it possible to determine in any point of space the value of magnetic induction produced by an infinitively small length of a conductor in which electric current is flowing.

In 1826, another French physicist, André-Marie Ampère, described mathematically the quantitative relationships between electrical and magnetic phenomena, w including the law that links the magnetic induction around an infinitely long straight-line conductor with the amperage of the electric current flowing in that conductor. The development of the science of electromagnetic phenomena was increasingly dynamic. The English physicist Michael Faraday introduced the concept of field force lines and made a claim that electric charges interact with each other by means of a field and in 1831 he discovered the phenomenon of electromagnetic induction, which can be used to generate an electric current. On the other hand, in 1839, the German physicist and mathematician Carl Friedrich Gauss developed, as an extension of the Coulomb's law, the basis for the theory of potential that linked the electric field with its source (i.e. an electric charge), and demonstrated that there are no like magnetic charges that would produce a magnetic field.

As Gauss's discovery indicates, magnetic poles always appear in pairs (N-S), forming so-called magnetic dipoles. Since single magnetic poles ("monopoles") do not exist in nature, separation of the poles of a permanent magnet is not possible. Breaking an N-S bar magnet in two does not produce an N magnet and an S magnet but, instead, two N-S magnets.

Of course, as was the case with electric charges, the opposite poles of a magnet (N and S) attracted (see Fig. 5a), and the like poles (N and N or S and S) repel each other (see Fig. 5b, c). As a result of the interaction, the field force lines are curved.

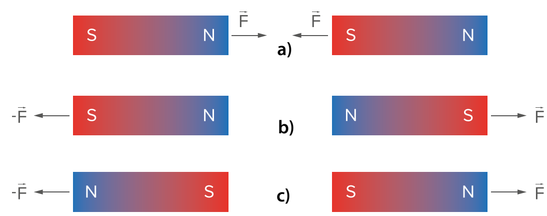


Fig. 5a, b, c. Interaction of opposite poles (a) and like poles (b, c). Author: Paweł Woźniak

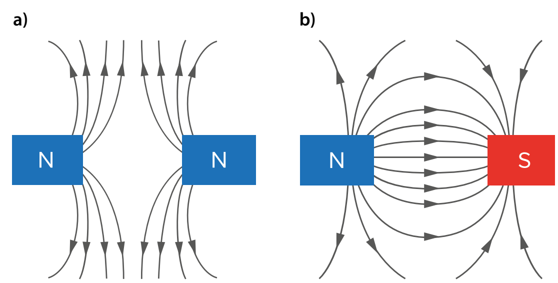


Fig. 6a, b. Magnetic field force lines around the like poles (a) and the opposite poles (b). Author: Paweł Woźniak

The phenomenon discovered by Ørsted, although of a very simple nature, is also commonly used nowadays in electromagnets. An electromagnet is composed of a coil, which is usually an assembly of multiple conductors, the shape of which is similar to a circle, and a core located inside the coil w to increase the force, with which the electromagnet is able to attract ferromagnetic materials.

The electromagnetic field undoubtedly has accompanied humans not only "always", but also everywhere, in every part of their lives. Humans, as well as our entire planet, are in the vicinity of a giant source of electromagnetic waves with a very broad spectrum, namely the Sun.

Fig. 7. James Clerk Maxwell (1831-1879)
Source: Wikimedia Commons

The interaction of a magnetic field with a conductor, in which electric current is flowing (discovered at the end of the 19th century by the Dutch physicist Hendrik Antoon Lorentz), is also commonly used in modern times, and on a large scale – e.g. in electric motors. As a result of the interaction of a magnetic field with a conductor with electric current, which also generates a magnetic field, a force is generated that enables an electric motor to do the work.

Electromagnetic field

The information presented above concerning static electric and magnetic fields can be summarized by saying that they are related to the source that produces them. The static field strength value does not change in time but changes in space, i.e. decreases as the distance from the source increases. What if the field is not static? Then this is an electromagnetic field that changes both in time and in space.

Mutual time and spatial relationships between the electric field E and the magnetic field H, which fully characterize the properties of these fields, were described by the British physicist James Clerk Maxwell in 1861.

Maxwell proved theoretically that both electricity and magnetism, as physical phenomena, are components and two kinds of the same phenomenon called electromagnetism. He unified the electrical and magnetic interactions. The mathematical description of an electromagnetic field proposed by Maxwell, which is now the classic theory of electromagnetism, carries a message that can be simply described as follows:

- A magnetic field that changes in time produces a spinning electric field. This is the so-called Faraday's law of electromagnetic induction.
- Moving charges (i.e. a current) and an electric field that changes in time, produce a spinning magnetic field. This is the so-called Ampère's law extended by Maxwell.
- The source of an electric field is electric charges. This is the so-called Gauss's law for electricity.
- There are no charges that are a source of a magnetic field (the magnetic field is sourceless). This is the so-called Gauss's law for magnetism.

The components of the electromagnetic field, i.e. an electric field and a magnetic field, can exist independently, provided they are do not change in time.

From a physical standpoint, **an electromagnetic field** is therefore a state of space, in which electromagnetic forces act on **a physical object** having an **electric charge** and an energy flow occurs. In each point of this space, the forces are described by two vectors that represent the fields changing in time: electric E and magnetic H. According to the principle of mutual induction, the time-variable electric field E causes the time-variable spinning magnetic field H, which then produces the time-variable spinning electric field E, and so on. As a result of subsequent continuous changes of the electric field and the magnetic field, **an electromagnetic wave is crated**.

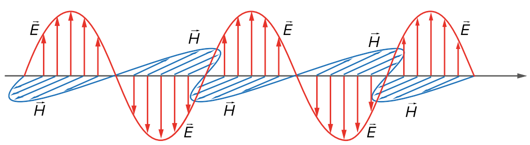


Fig. 8. Distribution of E field and H field.
Author: Paweł Woźniak

An electromagnetic wave, as a disturbance of an electromagnetic field, is an combination of a sinusoidally variable electric field (in which the field vector E vibrates) and a sinusoidally variable magnetic field (in which the field vector H vibrates), whereby the vibrations of the E field and the H field are fully synchronized and conforming in the phase. The field vectors E and H are perpendicular to each other and, at the same time, perpendicular to the direction of wave propagation.

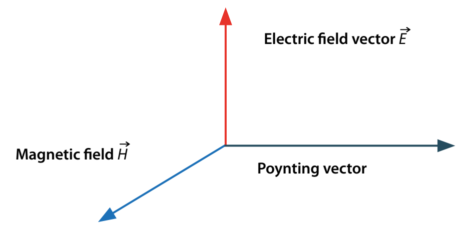


Fig. 9. Arrangement of the E and H field vectors in relation to the direction of propagation. Author: Paweł Woźniak

The mathematical description of the electromagnetic field proposed by Maxwell was verified and confirmed experimentally by the German physicist Heinrich Rudolf Hertz. In 1886, Hertz was the first person to generate, in practice, in laboratory conditions (an electric oscillator of his own design) an electromagnetic wave. By performing further experiments, he confirmed Maxwell's theoretical considerations. He also discovered that an electromagnetic field produced in one place can be received and recreated in another place – thus, he formed the basis for the development of radio communication. He demonstrated that the nature of their vibration and their susceptibility to reflection and refraction is the same as those of light and heat waves. As a result, he established beyond any doubt that light is an electromagnetic wave in a certain range of length.

Interestingly, Hertz seemed to underestimate the importance of his epochal discoveries. In 1890 he said: "I don't think that the wireless waves I discovered will have any practical use."[2] However, he was very wrong…

2 See: https://www.famousscientists.org/heinrich-hertz

I.2

From radio waves to gamma rays: the electromagnetic wave spectrum

Rafał Pawlak, Augustyn Wójcik

Length, frequency and speed of electromagnetic waves

Electromagnetic waves, just like regular mechanical waves, can be described by specifying the parameters that clearly characterize them: length, frequency and speed.

Wave length, denoted by *λ*, is the distance between any two consecutive wave crests. This parameter makes it possible to describe the waveform in terms of space. It is simply expressed meters [m], but usually, in practice, submultiple units are used:

- cm = 10^{-2} m = 0.01 m,
- mm = 10^{-3} m = 0.001 m,
- µm = 10^{-6} m = 0.000 001 m,
- nm = 10^{-9} m = 0.000 000 001 m,
- pm = 10^{-12} m = 0.000 000 000 001 m, or

multiples, especially the kilometer:

- km = 10^{3} m = 1,000 m.

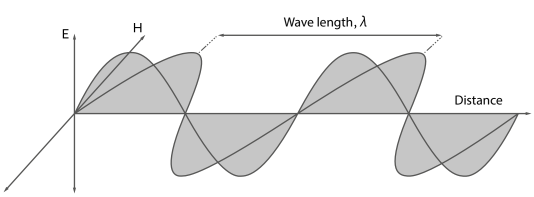


Fig. 1. Wave length – spatial dimension.
Author: Paweł Woźniak

Wave frequency, denoted by f, specifies the number of wave lengths that pass through a selected point in one second, i.e. how many times per second the electric field and the magnetic field have the same values. Wave frequency f can be described in terms of time and is linked to the wave period T with the following relation:

$$f = \frac{1}{T}$$

The period is expressed in seconds [s] and the frequency – in the unit [1/s], which is named hertz [Hz]. Usually, multiple units are used:

- kHz = 10^{3} Hz = 1,000 Hz, i.e. one thousand changes in one second,
- MHz = 10^{6} Hz = 1,000,000 Hz, i.e. one million changes in one second,
- GHz = 10^{9} Hz = 1,000,000,000 Hz, i.e. one billion changes in one second.

The relationship between the length *λ*, the frequency *f* and the speed *v* of the wave is the following:

$$v = \lambda \cdot f$$

In contrast to an acoustic wave, which is a mechanical wave, an electromagnetic wave does not need a material medium to propagate: it can propagate not only e.g. in air or water, but also in vacuum.

What is the speed of electromagnetic waves in vacuum? It is the highest physically possible speed, defined by the letter *c* and equal precisely to 299,792,458 m/s. Importantly, the speed of propagation of an electromagnetic wave does not depend on the frequency of the wave: radio waves, visible light, and X-rays travel through space with exactly the same speed.

The above relationship can, in the case of vacuum, be written in three equivalent forms:

$$c = \lambda \cdot f \qquad (1)$$

$$\lambda = \frac{c}{f} \qquad (2)$$

$$f = \frac{c}{\lambda} \qquad (3)$$

Because every day we are surrounded by air and not by vacuum, it is good to consider at what speed electromagnetic waves move in the air. It turns out that the speed is equal to about 299,700 km/s, which is only slightly – 90 km/s – less than *c* – the speed of light in vacuum.

Typically, for simplicity, the speed of light is taken to be with a certain approximation (excess) of 300,000 km/s. This means that in one second a an electromagnetic wave moving in vacuum travels the distance of approximately 300,000 km. For comparison: in one second, sound travels the distance of "only" 340 m (the speed of the sound in air is 340 m/s).

The speed of electromagnetic waves in various material media is always lower than the speed of light in vacuum, because it depends on the relative electric and magnetic permeability and on the conductivity, which characterize properties of a given material medium.

Knowing the relationship (2) and (3) between the wave frequency *f* and its length λ, associated with the speed of light *c*, it is possible to determine the quantitative relationship between these values – see the infographics on page 38.

Electromagnetic wave energy

An important characteristic of electromagnetic waves is their ability to transmit energy and to pass it to every body they encounter. This is very easy to verify: all one has to do is to remember how much the solar radiation (the electromagnetic waves emitted by the Sun) heat us on summer days.

Because in the case of an electromagnetic wave the carrier of energy is simultaneously an electric field and a magnetic field, the total energy of the electromagnetic wave is the sum of the energies carried by these fields. The energy stored in the electric field is equal to the energy stored in the magnetic field. The greater the strength of the electric field and the magnetic field, the greater the energy carried by an electromagnetic wave. To put it more precisely: the energy is proportional to the square of the strength of the electric field and the magnetic field.

The energy carried by the wave comes from the source of the wave. It can be stated that both in the electric field and in the magnetic field the energy is stored, in some sense. By way of propagation, a part of the energy transmitted by an electromagnetic wave can be lost by its conversion to another form, such as heat. Due to the loss of a part of the energy, the strength of the electric field and the magnetic field decreases and, as a result, the propagating wave carries less energy than it received from the source.

We are surrounded by electromagnetic waves that carry energy. They are produced not only by the natural sources around us, but also by every working electrical and electronic device. This energy can be acquired and converted into electricity using dedicated converters, and then used e.g. for powering miniature electronic devices, which are characterized by a low energy demand. This technique, which involves acquiring energy from the environment, is known as "Energy Harvesting." Of course, it is possible to use not only electromagnetic wave energy, but also e.g. mechanical energy of devices, energy of acoustic waves, and changes in electrostatic or magnetic forces. A flow of gases and liquids, pressure changes, and temperature differences can also be used.

Ionizing and non-ionizing radiation

Electromagnetic radiation can be divided according to the type of interactions of electromagnetic waves with matter. This division makes it possible to distinguish two basic types of electromagnetic radiation: **ionizing** and **non-ionizing**.

Ionization is a process as a result of which an electrically inert atom or molecule becomes an ion, which is an object with a non-zero electric charge. Such a change can involve detaching an electron from an atom or a molecule or one or more electrons breaking out of the crystal structure or connecting to an atom or a molecule. It can occur under the influence of various external factors, such as electromagnetic radiation. Although so-far we have described radiation as an elongated wave traveling through space, for over a hundred years we have known that it can also be treated as a flow of molecules by some energy. In the case of electromagnetic radiation, this is a stream of photons. The energy of a photon depends on the frequency *f* and is determined by the following relationship:

$$E = h \cdot f$$

The value *h* given in the formula is the so-called Planck's constant: $h = 6.63 \cdot 10^{-34}$ J · s.

The ability of photons to induce ionization increases with their energy, i.e. as mentioned above, as the frequency of the electromagnetic wave increases.

Ionizing radiation includes all types of radiation that are capable of ionizing a material medium. Electromagnetic ionizing radiation is defined as radiation whose photons have sufficient energy to detach electrons that are even the weakest bonded in atoms. In practice, this means that their energy must be greater than that of photons of visible light.

Non-ionizing radiation includes all types of radiation that are not capable of ionizing a material medium. Non-ionizing electromagnetic radiation is defined as radiation whose photons have energy less than or equal to that of the photons of visible light.

The conventional boundary between ionizing radiation and non-ionizing radiation is, therefore, determined by the boundary between visible light and ultraviolet light, i.e. the wavelength of $\lambda \approx 380$ nm = $380 \cdot 10^{-9}$ m, which corresponds to the frequency of $f \approx 8 \cdot 10^{14}$ Hz = 800,000 GHz.

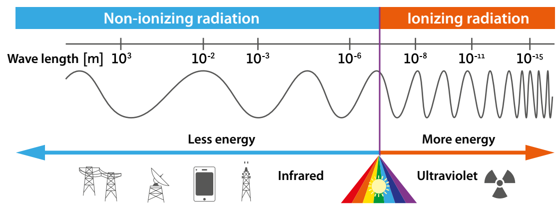


Fig. 2. Division of electromagnetic radiation into ionizing and non-ionizing radiation. Author: Paweł Woźniak

Since the upper value of the microwave spectrum of frequency of electromagnetic waves is 300 GHz, all microwave frequencies and, consequently, also radio frequencies, are not ionizing radiation. **Radio-frequency electromagnetic fields are non-ionizing, so they do not destroy the atomic structure of matter.**

In an ionizing radiation area dose accumulation occurs. It consists in the fact that the effects of exposure of a material to radiation increase with the time of the exposure. In living organisms, such effects are also observed when the radiation exposure ceases. In an area where non-ionizing radiation is present, the cumulative effect is not observed, and the effects on matter occur only during exposure to the radiation.

Electromagnetic wave spectrum

Some properties of electromagnetic waves, especially the way they interact with matter, depend on their length λ and thus on their frequency f. Because the properties of electromagnetic waves affect the possibility of their application in technology, they are most often divided according to frequency or length of the wave. Electromagnetic waves can therefore be ordered by taking into account both their frequency and their length. The resulting order is usually called the electromagnetic spectrum.

Most of the entire spectrum of electromagnetic waves is not perceived by humans. Nature has equipped humans with two "electromagnetic wave detectors": eyes and skin. Eyes allows humans to see electromagnetic waves in the visible light spectrum and the different frequencies of these waves allow, for example, the perception of the colors of objects around us. The skin, on the other hand, is sensitive to infrared – thermal radiation. Waves of other lengths are not seen or felt by humans, although they are equally real.

It should be added that the boundaries of the different types of electromagnetic waves are conventional and blurry. They should be treated as estimates, although they make it very easy to "move" across the entire spectrum of the electromagnetic waves. Traditionally, the following different types of electromagnetic waves are identified (see Fig. 3 and the infographics on page 38):

- radio waves,
- microwaves,
- infrared radiation,
- visible light,
- ultraviolet radiation,
- X radiation,
- gamma radiation.

Radio waves and microwaves

The conventional spectrum of radio-frequency and microwave electromagnetic field usually covers waves 1 mm to 100 km in length, i.e. frequencies in the range of 3 kHz to 300 GHz.

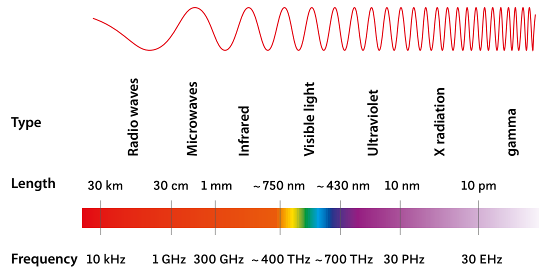


Fig. 3. The electromagnetic wave spectrum.
The wavelength and frequency values are approximate.
Author: Paweł Woźniak

Traditionally, the radio and microwave range is divided into very long, long, medium, short, ultra-short, decimeter, centimeter, and millimeter waves. They are used primarily in radio communications. The primary source of these waves is radio **antennas**. These are the most popular systems that use radio waves and microwaves:

- **AM** (*Amplitude Modulation)* radio uses long, amplitude modulated radio waves (see article I.5 on page 32). The frequency range from 530 kHz to 1,700 kHz is most commonly used. Due to the need to install antennas of very large sizes and to poor signal quality, AM radio is currently being abandoned.
- **FM** (*Frequency Modulation*) radio offers a much better sound quality due to the characteristics of the frequency modulation used. It uses frequencies in the range of 87.5 MHz to 108 MHz.
- **DAB** (*Digital Audio Broadcasting*) radio is the next generation of radio broadcasting which enables transmission of radio programs in digital form using the 174 MHz to 230 MHz frequency range.
- **RFID** (*Radio-Frequency Identification*) systems are used e.g. to control access to premises by equipping authorized persons with appropriate identification cards or to protect goods in stores against theft by affixing special labels on them. A magnetic field produced by the reader is used to transmit information. A similar operating principle applies to the NFC (*Near-Field Communication*) standard. Radio-frequency identification systems typically use 125 kHz and 13.56 MHz frequencies.

- DVB-T/DVB-T2 (*Digital Video Broadcast – Terrestrial*) is a commonly used standard for **terrestrial digital television**. Image and sound data, and additional information are encoded in digital form. Transmission is organized in the form of so-called multiplexes, i.e. single radio channels, within which data streams of several television programs are transmitted. Frequencies in which the television signal is broadcast in the DVB-T standard are in the ranges of 174-230 MHz and 470-790 MHz. The **satellite television** in the DVB-S/DVB-S2 (*Digital Video Broadcast – Satellite*) standard is organized in a similar manner. A satellite TV signal is transmitted at frequencies in the 10.7 GHz to 12.75 GHz range by satellites placed on a geostationary orbit.
- An important type of radio communications system is **mobile telephony systems**, which comprise a complete telecommunications infrastructure that allows subscribers to make wireless voice calls and data transmission in areas called cells. A cell is an area served by a single base station (see also Article I.6 on page 40). Due to their growing popularity, mobile telephony systems have been continuously developed for over ten years. Currently there are three digital mobile telephony systems: GSM (2G), UMTS (3G), and LTE (4G). 5G networks, which are now being designed, are discussed in a separate section of this publication (see page 105).
- **Wi-Fi** is a colloquial term covering several standards designed to create wireless local area networks. Devices that use Wi-Fi networks include computers, smartphones, tablets, game consoles, printers, and smartwatches. Networks of this type enable data transfer at the speed of up to several hundred Mbit/s and in a range of about 20 m inside buildings, depending on the version. Wi-Fi networks operate at frequency ranges of 2,400-2,483.5 MHz, 5,150-5,350 MHz, or 5,470-5,725 MHz.
- Many other wireless data transfer systems operate in the frequency range of 2,400 to 2,483.5 MHz, also briefly referred to as the 2.4 GHz band. The most popular of them are Bluetooth and ZigBee. A special feature of the Bluetooth system is the ability to easily create an "on demand" network between any two devices equipped with this interface. For this reason, Bluetooth is used, among others, in smartphones, smartwatches, tablets, and laptops. ZigBee, on the other hand is characterized by low energy consumption, which is very desirable in small battery-powered devices, e.g. in smart home systems or in battery-powered telemetry devices.

Fig. 4. A payment using the NFC standard.
Source: Wikimedia Commons

Waves with lengths from approx. 1 mm to approx. 30 cm are often called **microwaves**. Microwaves propagate relatively easily in the atmosphere; therefore, they are used in radar technology. Radar emits a signal in a specific direction and, based on a signal reflected from objects located in the monitored area, it is possible to determine the distance of the tracked object from the radar.

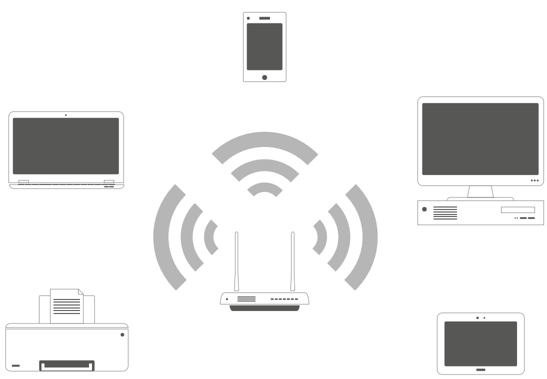


Fig. 5. An example of a wireless Wi-Fi network.
Author: Paweł Woźniak

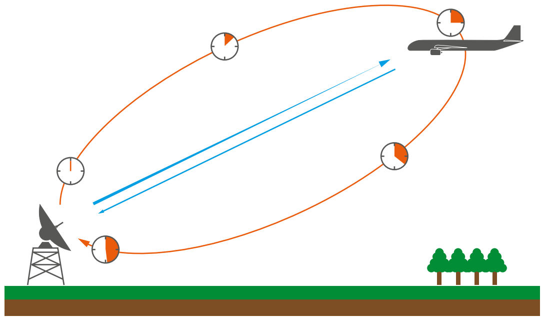


Fig. 6. Principle of operation of a radar.
Author: Paweł Woźniak

Many dielectrics, i.e. electrical insulators, absorb microwaves, which causes them to heat up. This phenomenon, used in specific frequency bands for industrial, scientific, and medical purposes, is utilized in microwave heaters, industrial heating devices, and medicine. Absorbed high-power microwaves, e.g. with the frequency of 2.45 GHz, cause an increase in the rate of vibration of water molecules, which results in an increase in the temperature of the object that contains these molecules. However, this is only possible at this frequency, which, moreover, must not be used in mobile telephony base stations.

In addition to telecommunication systems, attention should also be paid to the use of radio waves in medicine. In magnetic resonance imaging devices, waves with the frequency on MHz level interact with hydrogen contained in the human body, thus allowing for an accurate and non-invasive imaging of human body.

Infrared radiation

Infrared radiation is radiation with the wave lengths in the range between approximately 1 μm and 1 mm. It is also called thermal radiation, because one of its sources is hot bodies. Each body with **temperature** higher than absolute zero emits thermal radiation: for typical temperatures on the Earth's surface, this is infrared radiation, although e.g. The temperature of the Sun is so high that its thermal radiation is mainly in the visible light range, but also the ultraviolet light range (to be discussed below).For bodies with room temperature, the maximum radiation occurs at the wavelength of approximately 19 μm.

The higher the body temperature, the smaller the wavelength. This knowledge enables remote measurement of temperature and observation of objects with devices equipped with infrared sensors. The technique for recording infrared radiation emitted by objects is called thermal imaging. Thermal imaging enables, among others, imaging of objects in darkness.

The aforementioned properties of infrared radiation are used, among others, in firefighting, medicine, and many industries where remote temperature measurement is important.

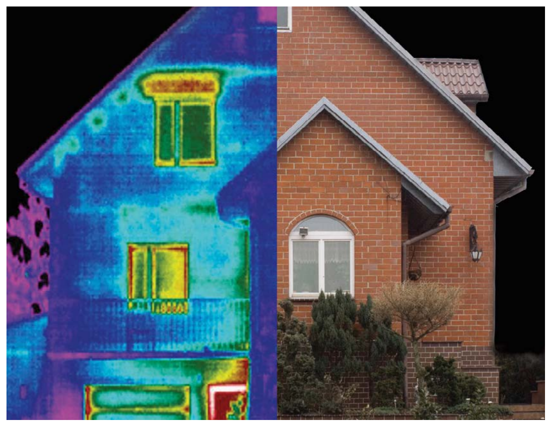


Fig 7. A photograph taken in the infrared wave range (left) and visible light range (right).
Source: Wikimedia Commons

In the infrared radiation band, astronomical and meteorological observations are conducted. This radiation is also used in heating technology. Is also used for data transmission in fiber optics and IrDA (*Infrared Data Association*) remote control systems.

Myth:

Every radiation is harmful to the body

The term "radiation" is a purely technical term used to describe various phenomena associated with energy transmission in the form of waves or particles in space or in another medium, e.g. thermal radiation. According to the way electromagnetic waves interact with matter, electromagnetic radiation is divided into ionizing and non-ionizing. Ionizing radiation includes those types of radiation that are capable of ionizing a material medium (e.g. radiation produced in nuclear reactors). A reminder: ionization is the process by which, for example, an electrically inert particle becomes a particle with a non-zero electric charge. Non-ionizing radiation is not capable of ionizing a material medium: its photons have too little energy to cause ionization. As a result, non-ionizing radiation has no negative impact on the body. It does not interfere with the cell structure, does not modify its components, such as the cell membrane or the nucleus, and does not affect their functions. It does not destroy the atomic structure of matter because it does not affect the bonds between atoms, which could lead to the breaking of particles and change their chemical properties. In addition, it has no cumulative effect, which means that the effect only occurs during exposure. Electromagnetic waves in the radio and microwave frequency ranges are non-ionizing.

Visible light

Electromagnetic radiation covering wavelengths from approx. 400 nm to 700 nm is called visible light. The retina of the human eye responds to this wavelength range.

Ultraviolet radiation

Ultraviolet radiation covers wavelengths approx. between 10 nm and 400 nm. It is considered to be ionizing radiation. Photons of ultraviolet radiation have high energy, so that this radiation can clearly influence the physical and chemical properties of substances, e.g. by breaking chemical bonds. The Sun is the strongest natural source of ultraviolet radiation. The upper layers of the Earth's atmosphere, especially the ozone layer, absorb most of this radiation, and only a small part of it reaches the Earth's surface.

Artificial sources of ultraviolet radiation are primarily mercury discharge lamps. Ultraviolet radiation is used in lighting technology, sterilization, forensics, an d chemical analysis. In certain substances, ultraviolet light causes fluoresce, which is used in banknote security techniques.

X radiation

X radiation is ionizing radiation with wavelength in the range of approx. 0.1 pm to 10 nm. It was discovered by Wilhelm Conrad Röntgen.

X radiation occurs in natural form. Its sources include stars, remains from supernova explosions and some pulsars. The most popular artificial source of X radiation is X-ray tubes. X radiation is used in medical diagnostics to make X-rays, in treatment of certain diseases using X-rays, as well as in substance chemical composition tests.

Fig. 8. An X-ray of a hand.
Source: Wikimedia Commons

Gamma radiation

Gamma radiation is the ionizing radiation emitted by radioactive or excited atom nuclei during nuclear transformations such as collisions of particles with antiparticles and elementary particle decay. Its wavelength is usually less than 100 pm. When passing through matter, gamma radiation is absorbed as a result of various phenomena.

Gamma rays are used to sterilize medical equipment. They are also used in **radiotherapy** for cancer treatment and in medical diagnostics. In the industry, gamma radiation is used to measure the thickness of materials that are difficult to measure by other methods, e.g. hot steel sheets and hot glass in smelters.

I.3

Power, absorption, scattering

Arkadiusz Kalinowski, Rafał Pawlak

In previous articles (see in particular article I.1 on page 8) it was explained that an electromagnetic field is formed as a result of interaction of two alternating fields: an electrical field and a magnetic field. As a result, by describing the components of these fields and the relations between them, it is possible to unambiguously determine the characteristics of the electromagnetic field as a physical phenomenon.

Measures of the strength of the electromagnetic field

The following vectors are the basic quantities, in addition to those already mentioned (wave length, frequency, and velocity), which enable quantitative description of the electromagnetic field:

- strength of the electric field $\vec{E}$;
- strength of the magnetic field $\vec{H}$; and
- density of the power $\vec{S}$ carried by the electromagnetic wave.

Similarly to a static case, the strength of the electric field is expressed in [V/m] (volts per meter), while the strength of the magnetic field strength is expressed in [A/m] (amperes per meter). Electric fields and magnetic fields, which make up the electromagnetic field, are closely related to each other – so the same can of course be said about the values that describe these fields. To put it simply (only for the values of those vectors) the following relationship occurs:

$$E = Z_0 \cdot H$$

As can be seen, the value of the electric field strength E is directly proportional to the value of the magnetic field strength H, and the proportionality coefficient is Z_0: wave impedance of open space. Wave impedance can be considered as the measure of how much a given medium "resists" propagation of waves. In vacuum (and approximately in air) it is equal to 120π Ω ≈ 377 Ω.

This relationship indicates that in order to clearly characterize the electromagnetic field in terms of value, it is enough to specify the strength of one of the two fields (e.g. the electric field), and the strength of the other field can be calculated. Knowing the strengths of both fields E and H, another quantity describing the electromagnetic field can be determined, i.e. the power density vector S. If the fields are mutually perpendicular (which, as mentioned in article I.1 on page 8, is typical of the electromagnetic wave), then the value of the power density vector can be determined according to the following equation:

$$S = E \cdot H$$

From the physical point of view, power density S defines the power of the electromagnetic wave per unit area. Therefore, power density S is expressed in [W/m^2] (watts per square meter).

Near field and far field

Generation of an electromagnetic field in the radio or microwave frequency range occurs around an element in which a time-variable current flows. This radiating element is called an antenna. The properties of the generated electromagnetic field change depending on the distance from the antenna. Taking into account the phenomena occurring at different distances from the antenna, the electromagnetic field is divided into two types: near field and far field. The boundary between the near field and the far field depends solely on the length of the electromagnetic wave produced (λ) and on the dimensions of the antenna D – it does not depend on e.g. the power of the electromagnetic wave. The boundary is located at distance R from the antenna, described by the following relationship:

$$R = \frac{2D^2}{\lambda}$$

Fig. 1 shows the boundary between the near and far fields (zones) is shown.

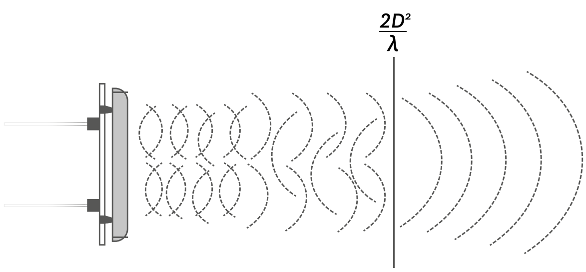


Fig. 1. An image of the near zone and the far zone.
Author: Paweł Woźniak

As the name indicates, **the near field** is observed in the vicinity of the antenna. In this area, the field is dependent on momentary values of currents and voltages in the antenna, and the relationship between the electric field and the magnetic field can be very complicated. The near field is present a distance less than R from the antenna. The strength of the magnetic field in this area is strongly dependent on the distance from the antenna and quickly decreases with the increase of this distance.

The zone defined as the distant field is the one where the electric field E and the magnetic field H can be described by the simple relationship given above ($E = Z_0 \cdot H$). The far field is present at a distance greater than R from the antenna. In the far zone, the field strength decreases proportionally to the distance from the antenna, and the distribution of the field is much easier to analyze.

Taking into account the typical dimensions of antennas used in practice the frequencies at which they work, and their location, it can be stated that in places commonly accessible to the public, we are dealing with the far field.

Propagation phenomena

Propagation of every wave (whether electromagnetic or mechanical) always takes place in a medium, but in the case of electromagnetic waves this medium can also be vacuum. The medium is an environment with identical physical properties which influence in a specific way the propagation of the wave (e.g. propagation direction, attenuation value). Therefore, the key media in which electromagnetic waves in the radio and microwave frequency range propagate are vacuum, the crust of the Earth, sea water, and the Earth's atmosphere.

Because radio waves, microwaves, and light are forms of electromagnetic waves, to describe phenomena occurring during propagation of radio waves and microwaves one can successfully apply phenomena commonly known from optics: reflection, refraction, diffraction, interference, and attenuation.

Reflection

Reflection is a sudden change in the direction of wave propagation at the boundary between two different media (see Fig. 2). Reflection of waves takes place in accordance with the according to the law of reflection which provides that the angle of incidence is equal to the angle of reflection.

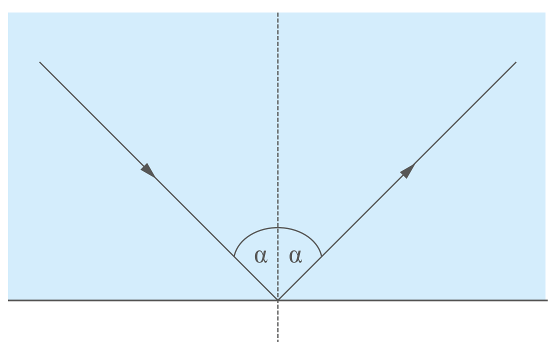


Fig. 2. The wave reflection phenomenon.
Author: Paweł Woźniak

Refraction

This phenomenon occurs on the boundary of two different media and causes a sudden change in the direction of wave propagation (see Fig. 3). Refraction may also occur in media whose physical conditions change continuously. In such a case, a curvature of the direction of the wave propagation will be observed. An example of such a medium is air, which may have variable humidity, temperature, or pressure. Refraction can be used for communication between antennas that are not in a line of sight.

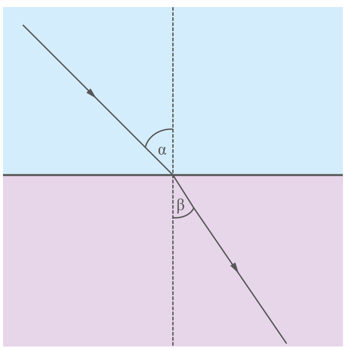


Fig. 3. The phenomenon of wave refraction. Author: Paweł Woźniak

In practice, usually both reflection and refraction take place at the boundary of two media. At the boundary of two different media, an incident wave is partly reflected and partly refracted: once it penetrates into the other medium, it continues to propagate in it. A simple illustration of this phenomenon is even a partial reflection of light on a window pane: one can see both one's reflection and one's objects behind the window.

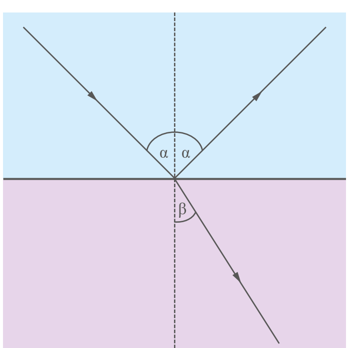


Fig. 4. Partial refraction and partial reflection of a wave. Author: Paweł Woźniak

Wave diffraction

Diffraction is a deviation of the path of a wave from the straight line direction that occurs at the edges of narrow gaps or obstacles in the path of the wave. For example, a wave that propagated in one direction, when reaching an obstacle containing a small hole, starts to spread in all directions.

Wave diffraction on a baffle and passage through a gap

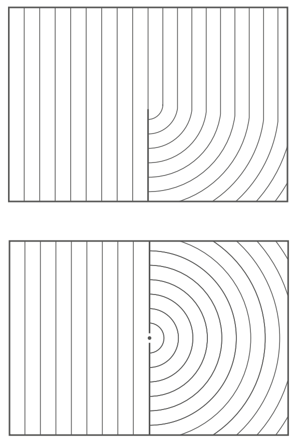


Fig. 5. Wave diffraction phenomenon. Author: Paweł Woźniak

The phenomenon of diffraction has been applied in radio communication: it enables, for example, sending a signal to valleys behind hills. A radio wave, once it encounters the top of the hill, bends and effectively propagates behind the hill, in the so-called radio shadow area. As a result, waves can have a much greater range than if they propagated along straight lines. Diffraction of a wave additionally causes its attenuation, proportional to the angle of diffraction.

Wave interference

Electromagnetic waves at the same point of space interfere with each other, which results in adding of their amplitudes. Adding of amplitudes can as well lead to an increase or a decrease of the amplitude of the resultant electromagnetic wave. A special case is the adding of waves of the same frequency (wavelength) amplitude, but different phases. In such a case, depending on the phase in which the two waves are in relation to each other, they can weaken or strengthen each other.

Interference of the waves that are:

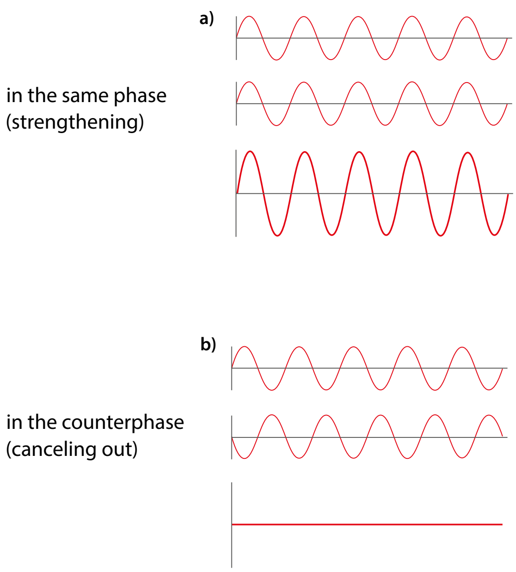


Fig. 6. Interference of waves of the same phase (a) and of different phases (b) – the resultant electromagnetic wave is shown at the bottom. Author: Paweł Woźniak

Attenuation

Attenuation is loss of wave energy in a given material medium, whereby the value of attenuation depends on the physical structure of this medium. When damping occurs, the energy of a wave leaving a given material medium is less than the energy of this wave at the time of entering the so-called "attenuation medium." Wave attenuation is associated with the phenomenon of absorption, i.e. absorption of the energy of an electromagnetic wave by the medium. The value of attenuation in air is influenced by the composition of the particles, i.e. humidity, percentage of oxygen and nitrogen, and the degree of contamination by other components. Wave frequency is another important factor influencing the value of wave damping. Usually the rule is that the higher the frequency of the electromagnetic wave, the greater its attenuation in a medium. Wave attenuation in open space is also significantly affected by the weather conditions (fog, rain, and heavy clouds).

Scattering

Wave scattering is a phenomenon that occurs at the time of wave reflection or diffraction on an uneven boundary of two media. Scattering has a similar effect to attenuation – the wave gradually loses its energy with the distance traveled. Unlike attenuation, the loss of energy occurs due to the division of the incident wave into a number of smaller reflected waves, which also propagate in different directions.

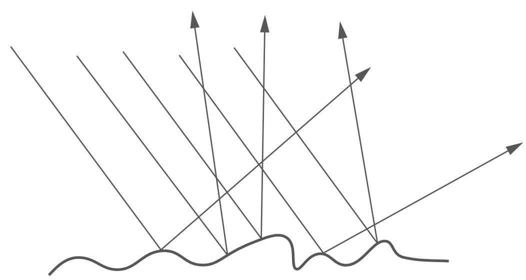


Fig. 7. Wave dispersion. Author: Paweł Woźniak

All the phenomena listed above can be observed during propagation of radio and microwave signals. Depending on the type of terrain, the density and height of buildings, the type of materials they are made of, and many other factors, individual propagation phenomena have more or less significant impact on the propagation of radio waves and microwaves. Furthermore, the critical factor that determines the occurrence of and intensity of the phenomena presented herein is the wavelength λ (also the frequency f) compared to the physical dimensions of the obstacle.

Propagation phenomena are pronounced when the wavelength λ is comparable with the dimensions of the obstacles (e.g. the dimension of the boundary of two media or the width of a gap). If the wavelength λ is greater than the dimensions of the obstacles, propagation phenomena are much weaker. For example, long and very long waves, the length of which may range from 1 km to 100 km, have a much greater propagation range than microwaves (e.g. ones with wavelength equal to 10 cm) because of the reduced number of obstacles they interact with. Consequently, e.g. a wave with the frequency of 1 GHz and the wavelength of about 30 cm can easily penetrate through thin walls of buildings, glass panes, and small everyday use objects, but is strongly damped by thicker walls, soil, and a dense forest. On the other hand, a wave with the frequency of 10 GHz and wavelength of approx. 3 cm is subject to much greater damping by walls, trees, and objects.

Mobile telephony currently uses frequencies from approx. 800 MHz to approx. 2.6 GHz – in this range, the wavelengths are approximately 33 cm to 10 cm, respectively. For such wavelengths, which are small compared to the dimensions of objects in the environment, scattering, diffraction, and reflection are practically always present.

An exemplary situation of the occurrence of propagation phenomena is described in Fig. 8.

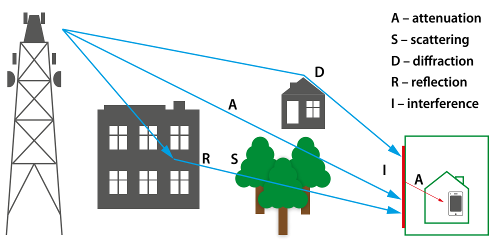


Fig. 8. An illustration of propagation phenomena.
Author: Paweł Woźniak

Fig. 8 illustrates along how many different paths, on which different propagation phenomena may be present, a radio or microwave signal can take from a transmitter to a receiver. This is a direct wave (A) that is damped only on the way from the transmitter to the receiver. Apart from the direct wave, there are: a wave reflected (R) from the buildings and a wave diffracted (D) on the edge of the building roof.

Each of these propagation phenomena has a different impact on the energy of the electromagnetic wave. The reflected wave can also be partially dispersed (R), depending on the roughness of the reflecting surface and the obstacles encountered (e.g. trees). Similarly, a diffracted wave can partially disperse its energy. Every radio wave or microwave, regardless of its diffraction or reflection, is damped (although in Fig. 8 this is indicated, for clarity, only for the direct wave). Because in reality radio waves and microwaves travel different distances, interference (I) of many radio waves and microwaves originating from the same source, but with completely different, random phases occurs at the point of their reception. Interference may result in partial or complete loss of signal at the reception point.

Electromagnetic wave propagation – technical consequences

Through many experiments and observations of the aforementioned propagation phenomena, it became possible to predict and precisely describe them and, as a result, to use them efficiently, so as to ensure effective transmission of radio and microwave signals of adequate quality between transmitters and receivers.

In the case of mobile radiocommunication, the situation is usually extremely complex because, although the base station antenna(s) is (are) in a specific location that has been appropriately selected at the network planning stage, the subscriber terminal antennas (i.e., in practice, mobile phones) are constantly changing their positions with their users. In this situation, the propagation conditions are constantly changing, which must be reflected in the way the network is designed (see article I.6 on page 40).

Network designers must take into account many factors related to the topography, the existing buildings, the location and height of the buildings, and the presence of woodland.

In typical rural areas with low density of buildings, the number of field obstacles is relatively small. It is therefore advantageous to place base station antennas at high altitude and to adjust the radio signal level to ensure proper coverage of the cell area. As a result, the radio signal covers a large area simultaneously and signal energy losses resulting from occurrence of unfavorable propagation phenomena are small. Usually, due to the lack of significant field obstacles, good direct wave propagation is achieved.

The situation in urban areas is completely different. Ensuring good direct wave propagation is more complicated, if possible at all. Tall buildings effectively damp radio and microwave signals. They also cause scattering of the signal, its diffraction and refraction, and the dense buildings and moving objects, such as buses, can lead to multipath propagation. In this situation it would be extremely inefficient to use the same base station distribution as in a rural area. The best possible direct visibility between base station antennas and user terminals can be achieved with a much denser distribution of base stations. In this solution, the relatively small distances between the base stations and user terminals enable transmission of signals with significantly reduced power (compared to stations operating in rural areas) and minimization of the negative impact of propagation phenomena.

Myth:

An antenna installed on the roof of a house is a threat to its inhabitants

The antennas used in mobile telephony systems have precisely shaped characteristics that determine the primary and secondary directions of emission of electromagnetic fields. A major part of the energy of the electromagnetic field is emitted in the space in front of and on the sides of the antenna. On the other hand, the downward emission of energy, directly under the antenna, is minimal. It can be compared to the emission produced by a home Wi-Fi router. There is also a legal provision (Regulation of the Minister of Environment of 30 October 2003) requiring installation operators to verify that electromagnetic field limits are not exceeded in locations accessible to the public. The verification consists in performing broadband measurements of the electromagnetic field strength (see article III.3 on page 89). Exceeding the permitted levels is prohibited. If it is found that the levels are exceeded, the operator must reduce the emissions of the base station accordingly. In the measurements carried out by the Provincial Inspectorates for Environmental Protection as a part of the State Environmental Monitoring, and also in the tests carried out during the annual measurement campaigns conducted by the National Institute of Telecommunications (NIT), no cases of exceeded limits in places accessible to the public were found, also in measuring points located at a short distance from antennas. An exception is one case in the measurement campaign of the NIT from 2017 (see article III.4. on page 96).

I.4
Natural sources of the electromagnetic field

Rafał Pawlak

Sources of natural electromagnetic fields, in which people have "always" lived, are the Earth and atmospheric phenomena, the Sun and cosmic phenomena, as well as every matter the temperature of which exceeds the temperature of absolute zero - which means every single matter.

In all points of our planet, there is a **natural magnetic field**, i.e. the so-called "geomagnetic field." It is basically considered to be a constant field, although – as it will soon be explained – it is not entirely true. The existence of this field on the surface of the Earth can be observed by everyone, using a simple instrument: a compass. Interestingly, the field surrounding us is in reality a combination of two components: an **internal magnetic field**, related to phenomena occurring in the Earth's core, and an **external magnetic field**, related to phenomena occurring in the ionosphere (the upper layer of the Earth's atmosphere) and in the magnetosphere (see below).

Earth's internal magnetic field

Until the end of the 19th century, it was believed that the deeply located strata of the Earth are built from extremely strongly magnetized deposits of iron compounds, which generate the magnetic field. Such a claim, however, turned out to be invalid. In 1895, the French physicist Piotr Curie discovered that once a certain limit temperature (today called the Curie temperature) is exceeded ferromagnetic substances, i.e. those which show their own, spontaneous, strong magnetization, lose their magnetic properties. Ferromagnets are used by us on a daily basis, e.g. in refrigerator magnets.

Because the temperature of the Earth's interior significantly exceeds the Curie temperature of substances known to man, the geomagnetic field cannot originate from a giant permanent magnet hidden inside our planet.

What is its source then? Currently it is believed that convection movements in the liquid outer core of the Earth cause the flow of electric eddy currents which produce the magnetic field. This is the so-called theory of self-excited **magnetohydrodynamic dynamo**, proposed in 1949 by the English geophysicist Edward Bullard. According to this theory, the natural dynamo of the Earth (geodynamo) is propelled by the convective movements occurring at the interface of the mantle with the outer core, while the eddy currents are produced by the Coriolis effect associated with the rotation of the Earth around its own axis.

Like all magnetic fields in nature, the magnetic field generated in the Earth's core obviously has two poles (see article I.1. on page 8). The geomagnetic poles are located near the geographic poles (which are determined by the axis of rotation of our planet), but are slightly offset in relation to them. The Earth's magnetic axis is deflected by approximately 11° from its axis of rotation and moves annually by an angle corresponding to the distance of several kilometers on the surface of the Earth.

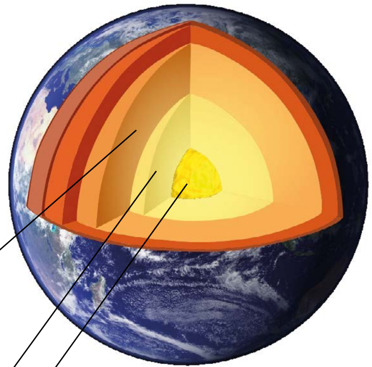


Fig. 1. Earth's internal structure.
Source: Wikimedia Commons

The magnetic field produced inside the Earth does not disappear on its surface, but spreads in the space around our planet. The area where the effected the Earth's magnetic field is present is called **magnetosphere**.

The magnetohydrodynamic dynamo theory explains the existence of the magnetic field also for other astronomical objects. A similar natural dynamo is a feature of, e.g. the Sun, which, like the Earth, has its own magnetic field, which is much stronger and changes much faster.

Earth's external magnetic field

The sources of the Earth's external magnetic field are phenomena occurring in the upper layers of the atmosphere and in the magnetosphere, related mainly to the activity of the Sun (the solar wind causes deformation of the magnetosphere) and to the changes occurring in the ionosphere as a result of the so-called atmospheric dynamo.

The **solar wind** is created by the huge amounts of high-energy charged particles ejected from the surface of the Sun. The Earth's magnetosphere forms an "umbrella" that protects our planet against the solar wind by causing the direction of this stream of high-energy particles to curve, thus repelling it from the Earth. As a result of interaction of the magnetosphere with the solar wind, the magnetic field undergoes some deformation, which is variable in time. Distortion of the magnetic field results in the formation in the conductive strata of the globe of so-called telluric currents which become sources of secondary magnetic fields.

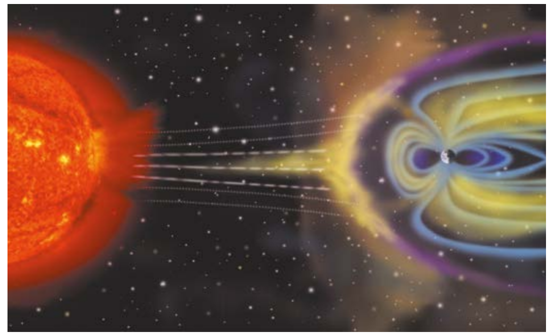


Fig. 2. The solar wind and the Earth's magnetosphere.
Source: Wikimedia Commons

Some of the deflected particles of the solar wind, however, permeate the Earth's atmosphere and causes the aurora phenomenon.

Fig. 3. An aurora. Author: Karol Wójcicki

However, the ionosphere and the magnetosphere do not constitute a barrier for radiation in the range from infrared to ultraviolet light (including visible light) and also in the radio and microwave frequency range of 30 MHz to 30 GHz (e.g. electromagnetic waves originating from extraterrestrial processes, mainly from the Sun, but also the microwave background of the entire sky). Consequently, it is considered that there are two frequency "windows" in the Earth's shield: an optical and a radio frequency window. Interestingly, the total energy density reaching the surface of the Earth on a sunny day, in the absence of clouds, is equal to approximately 1,000 W/m^2.

The **atmospheric dynamo** is a natural phenomenon consisting in the formation of an electric field in the ionosphere due to convective movements of partially ionized air. The electric field produced in this manner is variable and causes a flow of an electric current in the atmosphere, thus becoming a source of a variable magnetic field.

The magnetic field observed on the Earth's surface slowly changes in time. Its strength depends on the latitude and varies within the range of 24 A/m for most areas of low and medium latitude, up to 48 A/m in the vicinity of the Earth's poles. On the other hand, the changes in the external magnetic field observed on the Earth's surface are much faster, but its strength is negligible compared to the strength of the geomagnetic field. Because the Earth's magnetic field is dominated by the component originating from the internal magnetic field, it can be said that the magnetic field is approximately constant.

Earth's natural electric field

The source of the Earth's electric field is the charges distributed between the negatively charged surface of the Earth and the positively charged surface of the ionosphere. Such a system resembles the structure of a spherical capacitor: the surface of the Earth and the ionosphere act as covers for this capacitor, while the dielectric, whose thickness is about 50 km, is air. The electric field strength at the Earth's surface is on average equal to 100-150 V/m, although this value changes in specific places depending on the local weather. On the other hand, the difference between the potentials of the Earth's surface and of the ionospheric layer is equal to approx. 400 kV.

Unlike the magnetic field, the strength of the electric field depends on the latitude only to a small extent. This is related to the fact that the electric field of the atmosphere is constantly sustained by ongoing storms – although it may be difficult to believe, there are about 100 lightning strikes every second on the Earth's surface. Because the upper layers of atmosphere are a very good conductor, an even distribution of the potential of the ionosphere around the entire Earth is maintained and, as a result, the strength of the electric field at the Earth's surface is constant.

Fig. 4. Natural electric discharges.
Source: Wikimedia Commons

Storm clouds are the effect of electrical charges, which results from collision of cold and warm air masses, causing collision of ice crystals with drops of water. In the resulting clouds, the height of which can be up to several kilometers, loads are accumulated: negative in their lower parts and positive in their upper parts. The difference between the potential of the Earth's surface and the potential of a charged storm cloud can be up to 100 MV. It is so large that it results in piercing of air, ionization, and a lightning strike: the flow of a current of up to 100 kA for approx. 10-50 μs (microseconds). This produces a broadband electromagnetic impulse, the main part of the energy being in the up to 100 kHz band. The peak electric field strength at a short distance from a lightning strike (up to 1 km) reaches **10 kV/m** and up to **20 V/m** at a long distance (e.g. 30 km).

Fig. 5 shows the intensity of lightning discharges in an area of 1 km^2 during a year.

A very similar, in principle, phenomenon of electrification followed by a discharge leading to the equalization of potentials often takes place in people's vicinity. Just remember the effect of electrification of one's hair while combing or the snapping sounds sometimes heard when taking off a woolen sweater. A cat's hair reacts in a similar way and can reach the potential of several thousand volts when stroking.

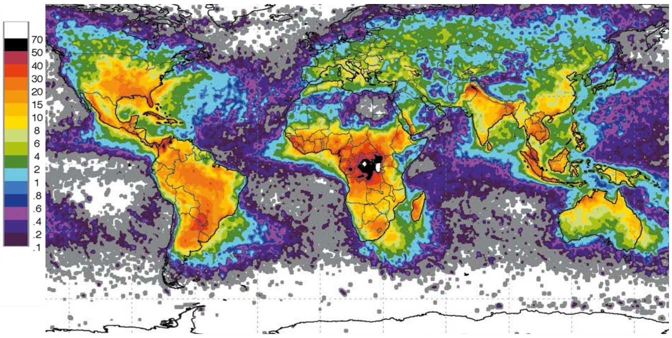


Fig 5. Frequency of lightning strikes on the Earth's surface. Source: Wikimedia Commons

Thermal radiation

Thermal radiation is generated spontaneously by any matter whose temperature exceeds absolute zero (0 K), i.e. –273.15°C. The source of this type of radiation is electrically charged particles moving inside of matter as a result of thermal motion. Thermal radiation is therefore a type of natural electromagnetic radiation whose wavelength depends only on the temperature. As the temperature increases, the length of the electromagnetic wave emitted decreases and, consequently, the frequency increases.

Objects with extremely low temperatures generate electromagnetic waves in the microwave frequency range. Objects whose temperature is close to room temperature – including humans – generate mainly electromagnetic waves in the infrared range, but some of them are in the radio range. The power density of the thermal radiation generated by humans at 37°C is approx. **2.5 mW/m^2**. On the other hand, objects whose temperature exceeds 600°C emit electromagnetic waves visible to the human eye, which are simply light. Depending on the temperature, the color of the glow changes: from dark red (approx. 650°C), through orange (approx. 1,100 °C), to white (above 1,400°C). Until recently, sources of thermal radiation with extremely high temperatures could be found in every house. What are these sources? Well, they are common light bulbs, whose tungsten filament, due to the flowing current, heats up to 2,500°C.

Myth:

The electromagnetic radiation that surrounds us is an artificial human product.

People live in an environment where there is always electromagnetic radiation from natural sources. Natural sources are not the product of human activity. They include: the Earth (which generates a magnetic field in its core), the Sun (which produces radiation in the range from infrared to ultraviolet, including visible light, as well as solar wind), atmospheric (related to lightning strikes) and cosmic phenomena, and literally any matter with temperature higher than absolute zero.

As a result of the development of civilization, humans began to produce artificial sources of electromagnetic field about 150 years ago. These sources fit into the existing spectrum of the natural electromagnetic field.

Fig. 6. Thermal radiation.
Source: Wikimedia Commons

I.5

Man-made sources of the electromagnetic field

Rafał Pawlak

Along with the development of human civilization, the electromagnetic environment has become enriched with sources other than natural, referred to as artificial sources of electromagnetic field. The first sources of this type were put in the environment relatively recently, just over 100 years ago.

Historical background

One could say that the current state of technical development, which actually determines the levels of electromagnetic field in the environment, is the direct outcome of the work carried out at the turn of the 20th century by Nikola Tesla (1856-1943) in the field of alternating current. Of course, a strong scientific foundation in this field had been built earlier.

Research in this area actually started in the late 16th century when William Gilbert, the personal physician of Queen Elizabeth I of England, as the first person in Europe, started research and experiments related to the phenomenon of magnetism and electrification of materials. In the year 1600, Gilbert has published a work entitled "On the Magnet and Magnetic Bodies, and on the Great Magnet the Earth," in which he presented the thesis that our planet is magnetized and, for this very reason, the compass needle points to the north (later this turned out to be untrue – see article I.4. on page 28). He also introduced new terms into the language that were new and revolutionary for that period of time, such as pole, force, and magnetic attraction. The experiments carried out by Gilbert were the pebble that, with time, caused an avalanche of work on magnetism and electricity. These issues started to be dealt with by many 17th- and 18th-century natural scientists, mathematicians, and physicists. This work culminated in 1873 with the "Treatise on Electricity and Magnetism" in which James Clerk Maxwell described his own uniform theory of electromagnetism, proving that electricity and magnetism are two kinds of the same phenomenon.

If it can be said that Maxwell closed the era of discoveries of classical electromagnetism, then Heinrich Rudolf Hertz, with his discovery of electromagnetic waves in 1886, started a completely new era of use of artificial electromagnetic fields, including for radiocommunication. Soon this new field of knowledge started to be successfully applied in practice.

After Samuel Morse built a simple two-wire telegraph in 1837, it was possible to instantaneously transmit simple information over long distances. The invention and patenting of Alexander Graham Bell's telephone in 1876 enabled efficient long-distance voice communication – thus, the barrier to long-distance communication was broken. Soon also the boundary between day and night was blurred. In 1879, electric lighting was first provided with the use of a light bulb, patented by Thomas Alva Edison. Three years later, in 1882, the world's first large city power plant and a 110 V direct-current electric lighting system was provided – on a massive scale at that time – to nine customers in lower Manhattan in New York City. This is how the bud of power engineering was created. Direct current motors and generators started to be used.

Soon it turned out that the methods of generation and transmission of direct current are inefficient and insufficient to satisfy the growing needs and the expectations of people in this respect were increasingly larger. The solution turned out to be alternating current, which was only be relatively easy to produce, but also, most importantly, could be effectively transmitted over long distances, due to the possibility of voltage transformation resulting in reduction of amperage and, consequently, of energy losses.

Nikola Tesla played a great role in the introduction of alternating current as in 1887 he filed patent applications related to distribution of energy in the form of alternating current. A fierce competition started between Edison and Tesla, referred to as the "War of Currents." It was won by Tesla who soon became famous as the designer of many devices for production and use of alternating current. His inventions include an electric motor and an alternating current generator, an autotransformer, a bicycle dynamo, a radio, a hydroelectric power station (on Niagara Falls), a solar battery, a turbine, and a high voltage transformer. Tesla was also the creator of the first radio remote control devices.

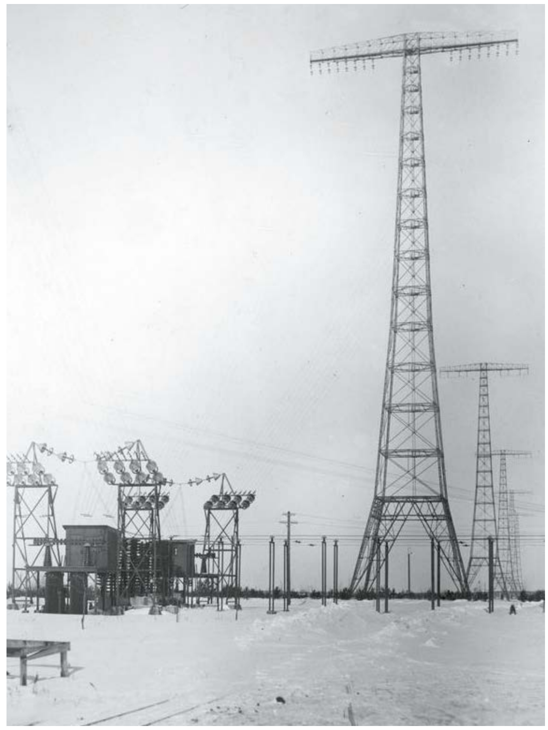


Fig. 1. Transatlantic Radio Station.
Source: Wikimedia Commons

Development of radio communication in Poland

The history of the development of radio communication in Poland dates back to the beginning of the Second Polish Republic. In October 1923, in Boernerowo near Warsaw (currently Bemowo, a district of Warsaw), a long-wave Transatlantic Radio Station was commissioned. It consisted of two transmitters (200 kW each) and an antenna installed on 10 steel towers, 127 m high, located over a distance of approximately 3.2 km. The station provided communications over the distance of approximately 6,400 km and generated an electromagnetic field with frequencies of approximately 14 kHz and approximately 16 kHz (which corresponds to an over ten kilometers long wave – see article I.1. on page 8).

The beginning of radio broadcasting in Poland dates back to 18 April 1926 when the Polish Radio station officially started its regular work. Since 2 January 1927, the Polish Radio has been using its own 10 kW, 269 kHz transmitter. The 130 m long antenna was installed on 75 m tall steel towers which, using the receivers available at that time, ensured a range of approximately 90 km.

As the radio became more and more popular and the number of subscribers reached 50,000 in 1927, a decision was made to build regional broadcasting facilities. As early as in 1927, stations were opened in Cracow, Poznań, and Katowice; in 1928 – in Vilnius, and in 1930 – in Lviv and Łódź. In 1929, the Polish Radio decided to build a high-power transmitter in Łazy near Raszyn. The 224 kHz, 120 kW station started its operation on 24 May 1931 and was the most powerful radio station in Europe at that time. Its antenna was installed on two 280 m tall masts and was the highest-installed radio antenna in the world. Due to the power and height of the antenna, the Polish Radio advertised the station in Raszyn near Warsaw as "THE MOST POWERFUL RADIO STATION OF THE WORLD."

Parallel to the development of radio broadcasting, in 1935 work started on the launch of a television station. Transmitting devices were installed in Warsaw's Prudential skyscraper, and the transmitting

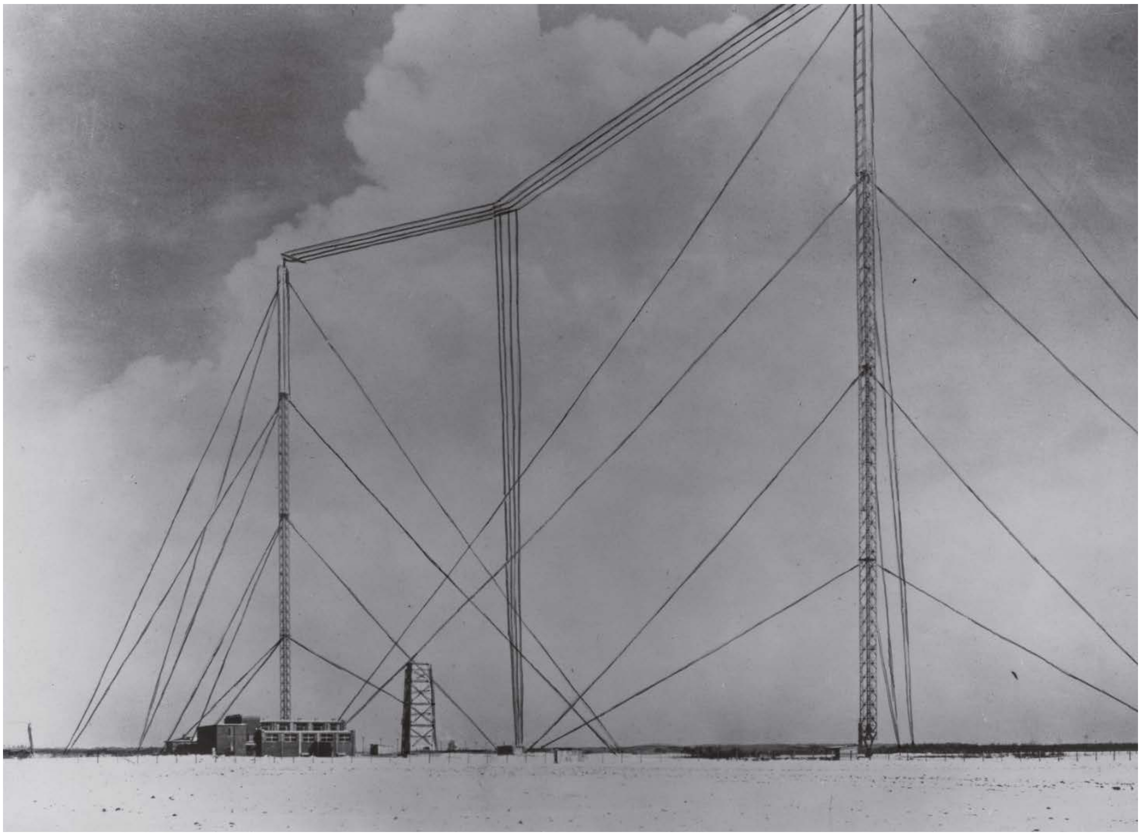


Fig. 2. The "Raszyn" Central Station of the Polish Radio in Łazy.
Source: A photograph from the National Digital Archives

antenna – on a dedicated support structure placed on the roof of that building. Test transmissions were conducted on 5 October 1938 and on 26 August 1939, but the research work was interrupted by the outbreak of World War II.

Electromagnetic fields around us

Every day, more or less consciously, we use electricity. One should keep in mind that any appliance powered by electricity, whether from the mains or from a battery, generates an electromagnetic field. An artificial electromagnetic field can therefore be a deliberate effect or a side effect.

All radio and microwave devices produce an intentionally generated electromagnetic field. These devices include large facilities, such as transmission radio and television stations, mobile telephony base stations, radiolocation and radionavigation stations, as well as much smaller devices, such as CB radio, radiotelephones used e.g. by emergency services, mobile phones, remote controls (e.g. for central locks in cars or for garage doors), RFID radio identification devices, Wi-Fi access points, DECT cordless telephones, devices with Bluetooth interfaces, and many others (see also the infographics on page 38). A special type of devices that intentionally generate electromagnetic fields is devices used in medicine: to diagnose patients and in physical therapy and rehabilitation.

An electromagnetic field that is a side effect of is produced by other appliances, e.g. electrical household appliances and devices for common use, such as vacuum cleaners, TV sets, computers, power drills, refrigerators, and even a bedside lamps. Moreover, the extensive network of 50 Hz high – and medium-voltage overhead power lines, including transformer stations, low-voltage networks, and electrical systems, which are used to supply electricity to customers, as well as the direct current railway catenary network, are also sources of artificial electromagnetic fields.

Given the number and location of electromagnetic field sources, the frequency and power ranges used, the propagation phenomena (refraction, reflection, diffraction, and interference of electromagnetic waves – see article I.3. on page 22), and the random factors associated with the use of certain sources, it can be concluded that the total strength of artificial electromagnetic fields in global terms is rather random than deterministic. However, in the vicinity of individual electromagnetic field sources, it is usually possible to estimate the strengths of the fields originating from these sources. Here are some examples:

- A 220 kV/50 Hz power line, values for the minimum permitted cable suspension height above the ground equal to 6.7 m:
  - electric field directly under the line: approx. 4.5 kV/m;
  - electric field at the distance of approx. 20 m from the line: approx. 1 kV/m;
  - magnetic field directly under the line: approx. 26 A/m;
  - magnetic field at the distance of approx. 20 m from the line: approx. 6 A/m;
- television set, radio receiver, fridge, coffee maker: < 0.05 V/m;
- microwave oven: approx. 3 V/m at the distance of 0.5 m;
- cordless screwdriver: approx. 0.5 V/m at the distance of 0.5 m;
- energy-saving bulb: approx. 3.5 V/m at the distance of 0.5 m;
- tablet with Wi-Fi: approx. 1.5 V/m at the distance of 0.5 m;
- Bluetooth speaker: approx. 0.3 V/m at the distance of 0.5 m;
- laptop: approx. 0.5 V/m at the distance of 0.5 m.

On the other hand, the broadband monitoring measurements carried out by Provincial Environmental Protection Inspectorates in 2017 (see also article III.4. on page 95) indicated that:

- in cities with population of over 50,000 inhabitants, the average electromagnetic field strength does not exceed 0.55 V/m;
- in other cities, the average electromagnetic field strength does not exceed 0.39 V/m;
- in rural areas, the average electromagnetic field strength does not exceed 0.21 V/m;

Artificial electromagnetic field generation mechanisms

In devices whose purpose is not deliberate generation of an electromagnetic field, the phenomena taking place are directly related to physics and are described by the Maxwell's laws (see article I.1 on page 8). Imagine a lamp connected to a power socket but switched off: the bulb is off – the current is not flowing, but the lamp is energized. Therefore, in the lamp's cable, due to the difference in potential, charges that producing an electric field are accumulated. When switched on, the bulb starts to emit light – the circuit closes and forms a continuous path for the flow of current, and the lamp is still live. Around the lamp's cable, a magnetic field is created by the flow of charges.

The lamp is obviously a very simple example. In reality, every cable of the electrical structure of a device is a source of an electromagnetic field: this applies not only the power supply cable, but also internal connection cables and external signal connection cables (e.g. USB or HDMI). Other sources of electromagnetic field are tracks on printed circuit boards that often carry high frequency signals (e.g., a clock signal for timing of a processor). In fact, devices produce an electromagnetic field with their entire structure.

In the case of devices that intentionally generate electromagnetic fields, an electromagnetic wave is also generated in accordance with the principles described by Maxwell's laws: however, it is not generated randomly but rather in a completely controlled manner, using specially designed electronic circuits. The electromagnetic wave generated in a transmitter is then not a side effect, but an intentional effect as its frequency and power are strictly defined.

A **radio transmitter** consists of multiple cooperating electronic components whose final task is to produce and emit radio waves carrying useful information, such as audio signals or digital data. The structure of a transmitter can be divided, in a simplified way, into five interconnected blocks.

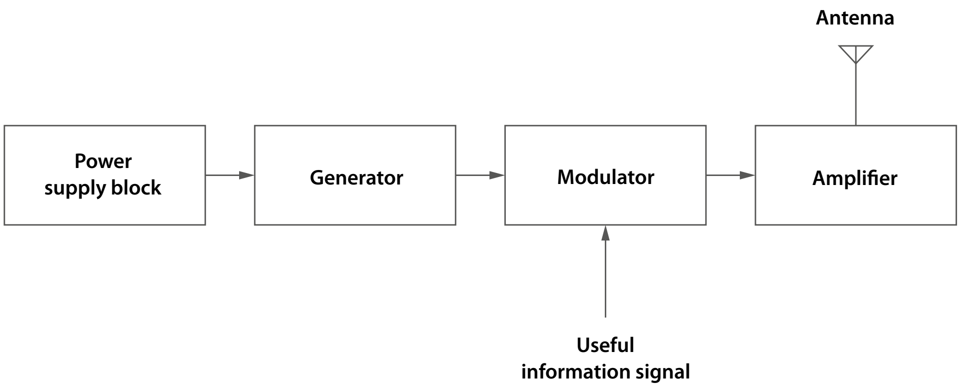


Fig. 3. Simplified block diagram of a transmitter.
Author: Paweł Woźniak

1. **Power supply block**: the source of the electricity required for the correct operation of the transmitter.
2. **Generator**: the heart of the transmitter, it produces a periodic, oscillating AC electrical signal in the form of a sine wave of a specific high frequency (usually called carrier wave) at which the transmitter operates.
3. **Modulator**: it superimposes the low-frequency useful information signal (called modulating signal) on the high-frequency carrier wave signal, which results in changes of a parameter of the high-frequency signal in accordance with the changes of the modulating signal. Because the carrier wave is described by three parameters (amplitude, frequency, and phase) that can be influenced, there are three types of modulation: amplitude, frequency and phase. For example, amplitude modulation (AM) consists in a change of the amplitude of the carrier wave signal in proportion to the momentary value of the modulating. In simple terms, the wave becomes alternately "stronger" and "weaker," and the consequence of the "stronger" and "weaker" periods is the information contained in the signal.

The above-mentioned case illustrates analogue modulation. In modern devices, on the other hand, digital modulation is used: unlike analogue modulation, it uses binary information in the form of bits (logical states) instead of continuous information. This results in a signal perfect for communication with computers: instead of a continuous "wave landscape," a sequence of zeros and ones is transmitted.

In this case, too, modulation consists in a change of the amplitude, the frequency, or the phase of the carrier signal, but in a stepwise manner, referred to as "keying." This is how the simplest digital modulations, i.e. ASK (*Amplitude Shift Keying*), FSK (*Frequency Shift Keying*), and PSK (*Phase Shift Keying*), are performed. In the case of the ASK modulation, the keying consists in that certain amplitude of the carrier wave signal is assigned to the logical state "1" and a different carrier wave signal amplitude is assigned to the logical state "0".

The modulations used in modern radio communication systems, e.g. mobile telephony, are

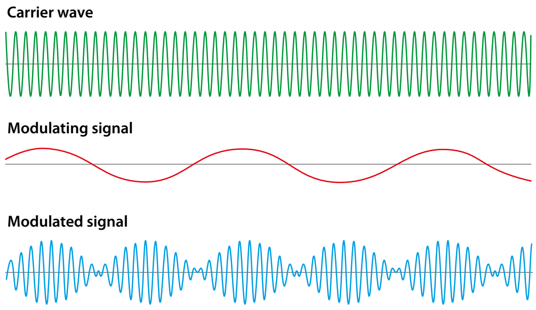


Fig. 4. Analogue amplitude modulation.
Author: Paweł Woźniak

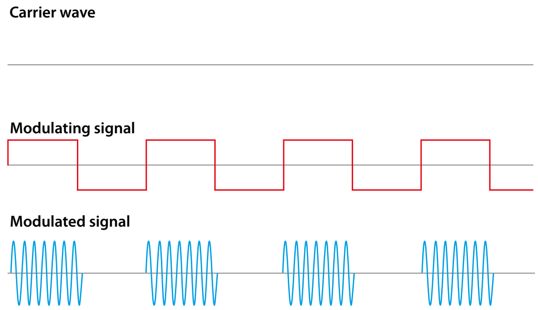
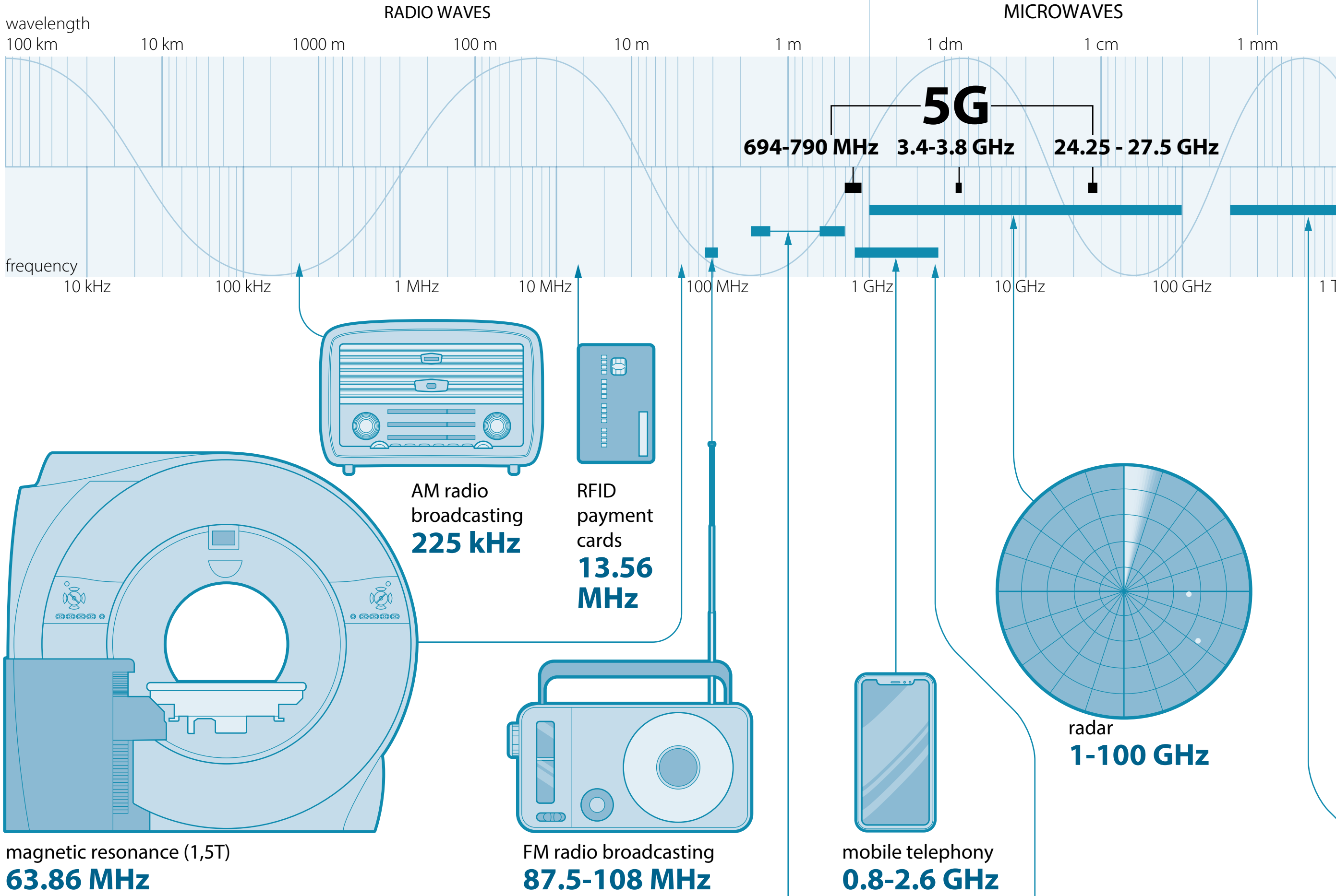


Fig. 5. Digital amplitude modulation.
Author: Paweł Woźniak

much more complex combinations or variants of the above basic signal modulation methods.

4. **Amplifier:** increases the power of the modulated carrier wave, makes it possible to determine the appropriate level of the transmitted signal.
5. **Antenna:** converts the modulated and amplified carrier wave into an electromagnetic wave emitted into space: consequently, it is necessary for radio transmission.

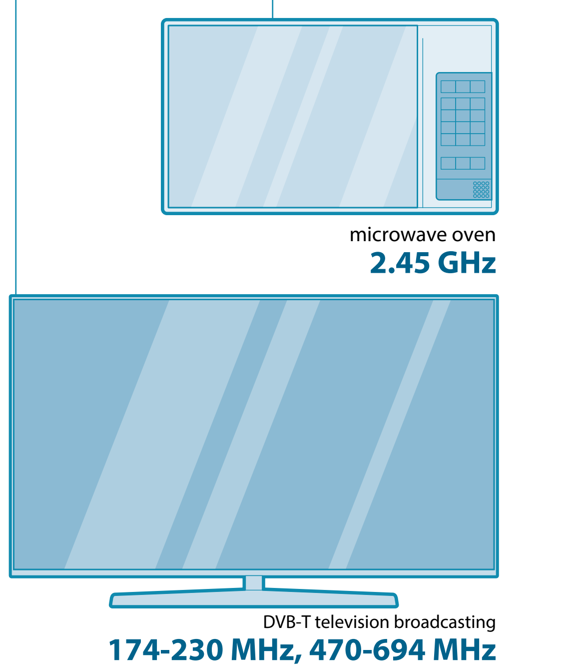
SOME APPLICATIONS OF ELECTROMAGNETIC WAVES

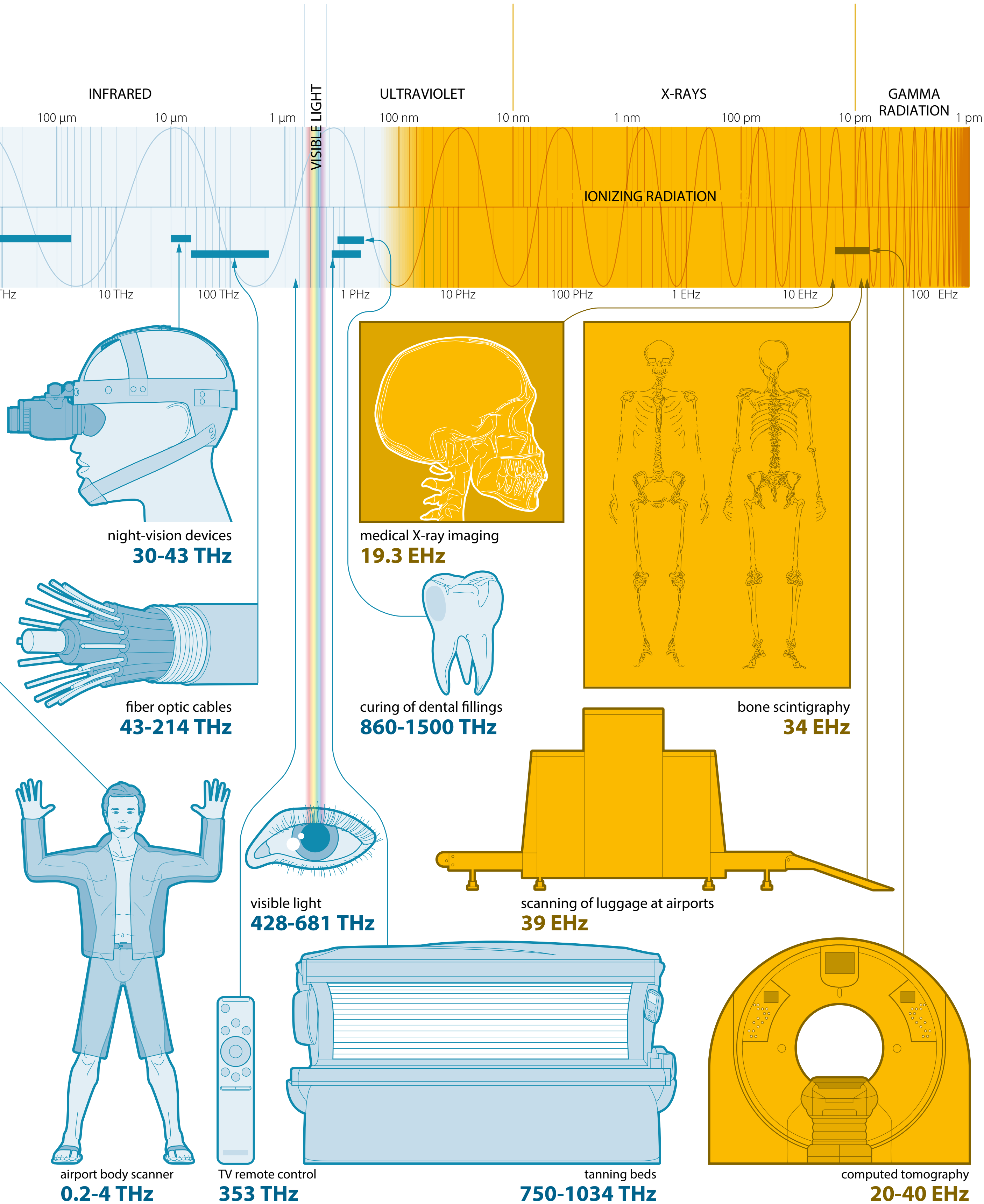


There are two basic parameters of electromagnetic waves: wavelength and frequency. These are actually two different ways to say the same thing.

An electromagnetic wave has the shape of a sinusoid and the simplest way to describe is to state the length of the wave, which is simply the distance between neighboring crests in meters (micrometers, nanometers, kilometers, etc.).

Because electromagnetic waves travel with the speed of light, each of their characteristic points – for example the crest – moves with that speed, which is equal to 300,000 km/s. Imagine that you are standing in place and counting how many times per second the crest of the electromagnetic wave passes next to you. If the wavelength was 300,000 km (this would be a rather unusual, extremely long radio wave), the crest would pass you exactly once per second. This corresponds to the frequency of 1 hertz. If the wavelength was half as large, the crest would pass you two times per seconds and the frequency would be equal to 2 Hz, and so on.




INFRARED
VISIBLE LIGHT
ULTRAVIOLET
X-RAYS
GAMMA RADIATION
100 µm
10 µm
1 µm
100 nm
10 nm
1 nm
100 pm
10 pm
1 pm
IONIZING RADIATION
THz
10 THz
100 THz
1 PHz
10 PHz
100 PHz
1 EHz
10 EHz
100 EHz
night-vision devices
30-43 THz
fiber optic cables
43-214 THz
airport body scanner
0.2-4 THz
TV remote control
353 THz
visible light
428-681 THz
medical X-ray imaging
19.3 EHz
curing of dental fillings
860-1500 THz
bone scintigraphy
34 EHz
scanning of luggage at airports
39 EHz
tanning beds
750-1034 THz
computed tomography
20-40 EHz

I.6 How does a mobile phone work?

Jakub Kwiecień, Rafał Pawlak

Cellular telephony is one of mobile radio communication systems. It is one of the most dynamic branches of telecommunication that use radio waves, and its users are individuals, businesses, and public institutions. Currently mobile phones are used by more than 92% of Poles (as of July 2017 – a CBOS report), with more than half of them being smartphones, and their share continues to grow dynamically. The increasing number of devices and their applications constitutes a challenge to the limited radio frequency resources, which results in a constant need for the development of the technology to increase the capacity and bandwidth of the network. A mobile phone has become not only the primary means of contact, but also a tool for work and entertainment. However, we rarely stop to ask how it works.

Why is the phone "cellular"?

The idea of a cellular system first arose in the 1940s in American laboratories of the Bell company. Until then, the demand for a communications system in a given area had been met by using only one transceiver device operating with high power and covering the entire area of the system. The innovation consisted in dividing a large area into much smaller areas, called cells, whereby the center of each cell was a device of lower power.

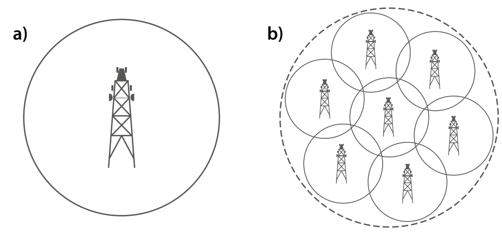


Fig. 1. Implementation of a radio system using: (a) one high-power base station, (b) multiple low-power base stations. Author: Paweł Woźniak

The fundamental reason for dividing the area into cells is the insufficient capacity of a system (capacity is the maximum number of supported terminal devices, such as a mobile phone) that comprises only one high-power base station. The size of the cell covered by a base station is many times smaller than the size of the area of the entire system, so it can operate with much lower power. Importantly, multiplication of the transmission powers do not proportionally increase the area of the radio signal coverage. As the power of the terminal device is much lower than that of the base station, it would not be possible to effectively maintain a radio connection toward the base station.

In a cellular system, adjacent base stations operate at different frequencies. As shown in Fig. 2, identical frequencies (symbolically described by numbers 1-7) in the area of one cellular system can be used multiple times. The method of assigning frequencies to specific base stations minimizes the risk of interference between neighboring base

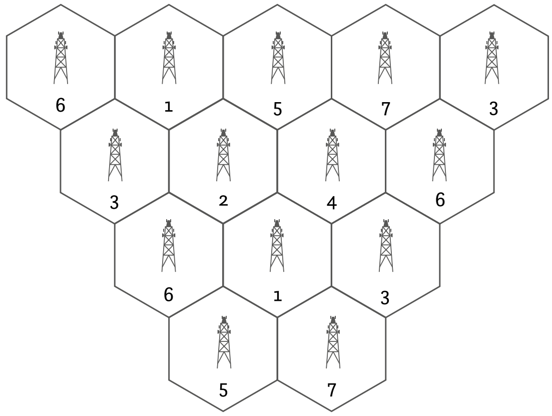


Fig. 2. Division of a telephony system into cells. Author: Paweł Woźniak

stations. The cell structure also allows for flexible system design, taking into account the characteristics of the area, such as the expected user density and the volume of traffic generated in the network.

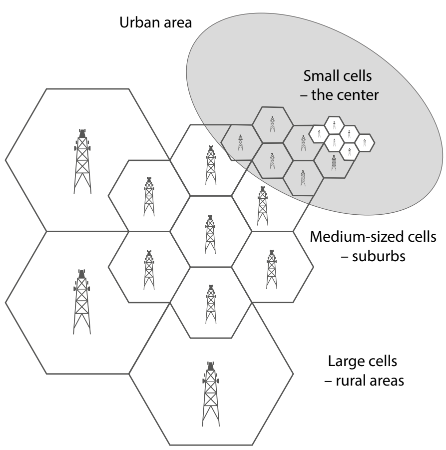


Fig. 3. Coverage of the system with cells according to the characteristics of the area. Author: Paweł Woźniak

Another essential feature of cellular systems, which distinguishes them from radio or television systems, is the way point-to-point transmissions are implemented. In cellular systems, the terminal can move both within its cell and in the entire system. This results in the need to provide a mechanism for automatic interception of communications by a new base station when the terminal leaves the area of one cell and moves to the neighboring one. This mechanism is referred to as "handover", i.e. the transfer of a call.

Mobile phone operation principle

Modulation

The first phenomenon that occurs in the process of voice transmission by radio waves is the conversion of air vibrations by the membrane in the microphone into, in simple terms, electric current vibrations. In 1G telephony (NMT system), this signal was routed to an analogue frequency modulator (FM) system. 2G (GSM system), 3G (UMTS system), and 4G (LTE system) telephony (see article IV.1. on page 106) uses digital transmission and various types of digital modulation.

Signal transmission

The next step is the transmission of the signal using radio waves. Some radio devices, such as CB radios, communicate with each other using radio waves directly and do not require network infrastructure for proper operation. The situation is different in the case of mobile phones, which require a dedicated network infrastructure to work properly because they never connect directly to each other.

The element of the entire broadly-defined cellular system that is always the closest to the user is the **terminal**. A terminal is any device that uses a cellular network. A terminal can be a data transmission modem attached to a computer to enable using the Internet or an IoT (Internet of Things) device that transmits data from sensors to its control panel. However, a vast majority of terminals are user devices such as mobile phones and smartphones. Modern multi-system terminals, compatible with most of the standards offered by operators, work automatically by switching between systems without the user's knowledge and the need for the user's interaction.

The calling user's terminal transmits data at a certain frequency and makes a call to the nearest base station that receives the signal at that frequency. Base stations are the most visible element of the complex mobile telephony network infrastructure – more information about them can be found in further in this article. Depending on the system, the base stations have different names – for GSM it is BTS (*Base Transceiver Station*), for UMTS it is NodeB, and for LTE it is eNodeB.

Then, through many different modules and devices that form the so-called **radio access network (RAN)** and the **backbone network**, the call reaches a specific base station, in the range of which the terminal of the user receiving the call is located. Now this base station transmits the signal at a certain frequency and connects to the selected terminal that receives the signal at that particular frequency. The connection is set. From the user who received it to the user who initiated it, the connection follows an identical path, but in the opposite direction.

The backbone network includes:

- a switched call/package switchboard – responsible for transmission of calls or data packets along specific paths;
- a register of devices – a list of registered telephones based on IMEI identification numbers;
- a register of own subscribers – contains the data based on which it recognizes system users (based on a SIM card);
- other elements responsible for correct operation of the system, setting up of calls, operation of devices, and enabling cooperation with other systems (interfaces to other networks).

User identification in the network

Telephone users are identified in the network by their SIM (Subscriber Identity Module) cards. A complete, useful terminal consists of a physical device and a SIM card inside it. This is a small size chip card whose dimensions gradually decrease with the development of the technology, from the original credit card size to the nanoSIM cards with the dimensions of approx. 12 mm by 8 mm. A SIM card used to identify the subscriber through the network therefore acts as an access key. It can also store small amounts of data, such as contacts and text messages.

Currently, users often change terminals to new models, and thanks to the separation of the identification function via the SIM card, changing the terminal does not cause the need to change the phone number – it is enough to move the SIM card to the new terminal. A telephone without a SIM card has a limited functionality with regard to use of mobile telephony network services. According to the specification, such a device can be used to make calls to emergency numbers – 112 in Poland (calls to the emergency number are given a higher priority and, as a result, in the event of excessive network load, the radio resource is assigned to them faster). A SIM card can be additionally protected by a PIN (*Personal Identification Number*) code so that an unauthorized user cannot connect to the network using the card.

Base station

A base station of the mobile telephony system is equipped with a set of antennas, which are mounted on a support structure, such as a mast or a tower placed on the ground or on the roof of a building, or integrated in a church tower structure, etc. Antennas used in mobile telephony solutions are usually installed on masts in three sets. Each set is responsible for covering a sector within the angle of about 120° (this is why antennas of this type are called sector antennas) in a strictly defined direction, called azimuth. Sector antennas, due to the need to cover a larger area with the signal, mainly at a small distance from the ground surface, are in slightly deflected from the vertical and lean toward the ground surface, i.e. the places where users are located.

Antennas are connected to transceivers with antenna cables. In the traditional solution, these devices are usually located in a container set at the base of the building or in a designated room, and the antennas are connected with long, heavy, thick, and rigid cables (so called "feeders"). In modern solutions, miniaturized transmitters and receivers are used, which are installed directly on masts or towers, at a small distance from antennas. This makes it possible to use antenna cables (so-called "jumpers") that are short, thin, light, and flexible.

Fig. 4. Types of antennas in a mobile telephony base station. Source: own NIT data

The field generated by the terminal – e.g. the mobile phone of a given user – often dominates locally over the field generated by the base station.

Next, the radio signal is digitized and then transmitted to the backbone network, either by means of a fiber optic cable, or using a radio link.

Radio link antennas, installed at a certain distance from the sector antennas, whey work at microwave frequencies (between ten and a hundred GHz) and emit the signal only in a narrow beam precisely directed toward another radio link antenna. Radio link antennas are not designed to establish calls with users within cells and, consequently, they are not tilted toward the ground.

Power control

The digital mobile telephony systems that are currently in use employ power control mechanisms whose primary function is to keep radio signal emissions on a minimum level sufficient to maintain services (e.g. calls) on the required QoS (Quality of Service) level. In other words, the terminal works with the lowest possible power sufficient to keep the required quality level.

The power control procedure in the GSM system (2G, see also article IV.1. on page 106) consists in measuring the transmission quality during a call based on the error rate of the signal received by the base station from the terminal and in transmission of the results to the base station controller, which, on this basis, twice per second, gives the command to change or maintain the level of the signal transmitted by the terminal. As a result, as the terminal approaches the base station, the terminal reduces the power of its transmitter. From the point of view of efficiency, this is intended to reduce the probability of interference in the system and to reduce the energy consumption from the battery.

For example, a terminal that is located at the boundary of a large cell, e.g. in a suburban area, transmits with maximum power. When the terminal moves to a smaller cell in an urban area, the distance between the terminal and the base station decreases, thus enabling the reduction of the power of the terminal.

Another important effect of the power adjustment procedure is the reduction of exposure to electromagnetic fields in the surroundings of the

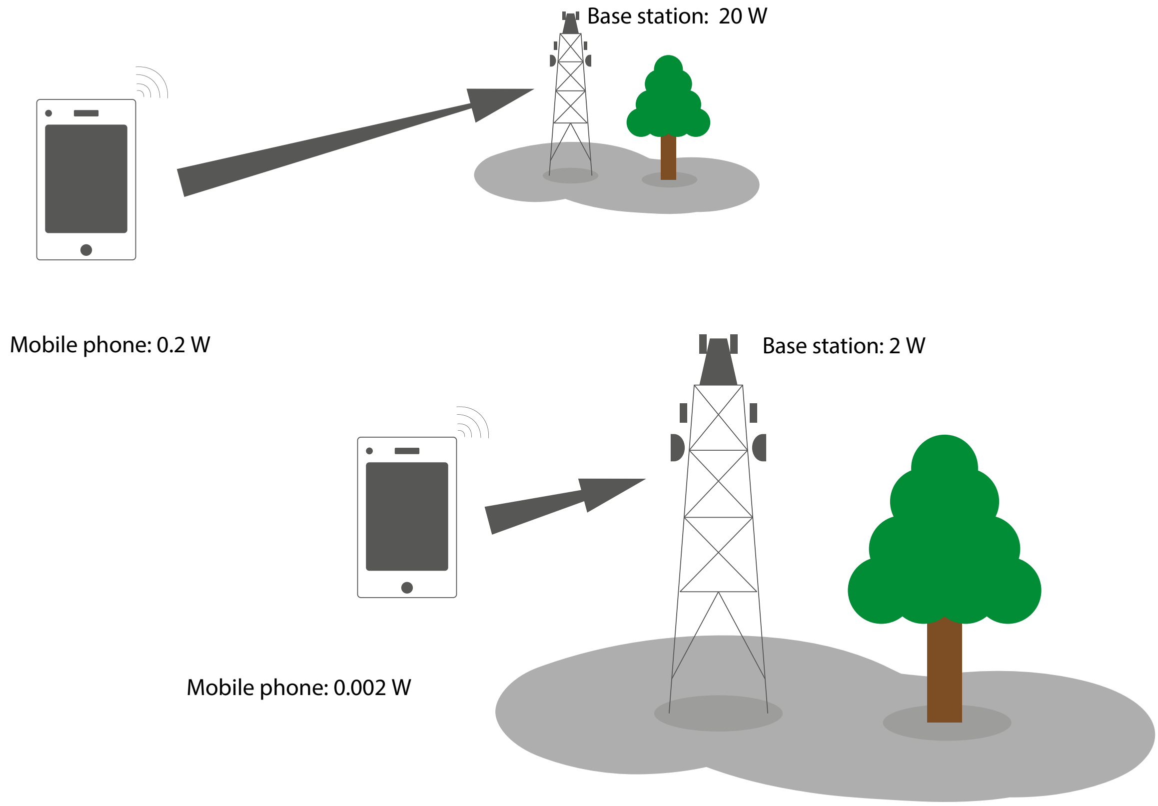


Fig. 5. The effect of the distance from the base station on the transmitting power of a mobile phone.
Author: Paweł Woźniak

terminal. It should be noted that the field generated by a terminal often dominates locally over the field produced by a base station. One should keep in mind that the radio signal emitted by both the base station and the terminal quickly attenuates as the distance increases. Consequently, the greater the distance from the base station, the lower the actual strength of the electromagnetic field originating from the base station: at the same time, the terminal – in order to maintain the required QoS quality level – must transmit with a greater power, thus producing locally, in the user's immediate vicinity, a stronger electromagnetic field.

Subsequent standards require increasingly lower terminal power. For 1G, this power was in the range of 6-15 W, for 2G it was already 1-2 W, while the typical transmitted power of terminals in the 3G and 4G systems is only 0.25 W and 0.20 W respectively. This is accompanied by increasingly sophisticated power control mechanisms – e.g. in the UMTS system, power is adjusted 1,500 times per second for both the terminal and the base station. This results from the continuation of the basic approach, which consisted in minimization of the power of the signals emitted by mobile telephony base stations and mobile terminals that is necessary to provide the service at the assumed quality level. Introduction of advanced signal power control mechanisms becomes an increasingly important issue with the development of the technology.

Conclusions

Mobile telephone systems now provide a much wider range of services than its original purpose, i.e. transmission of a speech signal to users moving within a large area. The GSM standard already provides a telephony service through the transmission of data containing digital representation of a speech signal. The phrase "mobile telephony" is strongly rooted in our reality and still, looking at a mast with antennas, we talk about mobile telephony base station. In reality it is a base station of many mobile communication systems, in which the telephone service has a decreasing share, and the scope of data services for Internet access, TV and radio broadcasting, and the operation of a growing number of user applications is dynamically increasing.

Myth:

More base stations mean higher intensity of electromagnetic field

The idea behind the cellular system is to divide a large area into many much smaller areas, called cells. In the center of each cell there is a base station whose transmitting power is much lower than that of a single station, which would have to cover the entire large area. The more base stations, the smaller the area of the cell that needs to be covered by the radio signal and, consequently, the power transmitted by individual base stations. If the transmission power of the base stations was too high, this would result their mutual interference and the system could not function effectively. The number of base stations also determines the power with which the subscriber terminals (e.g. mobile phones) work. As the number of base stations increases, distances to subscriber terminals decrease and, consequently, the terminals can operate with lower power. A reduction of the emission power of base stations and subscriber terminals leads to a reduction in the strength of the electromagnetic field.

Supervisor
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II. *Biology and medicine*

Introduction

- Electromagnetic waves are absorbed by matter in various ways. The same amount of energy can have different effects. For example, a sufficiently large dose of X-rays delivered in a short period of time can cause death, while an identical dose delivered over a longer period of time in the form of infrared radiation can be completely harmless.
- Non-ionizing radiation causes mainly the so-called thermal effect, i.e. simply heating up of the body, mostly of the skin and surface layers. The human body controls its temperature and responds to its local rise, e.g. by increasing blood flow, which results in faster removal of heat from the heated tissue.

  - The health effects of electromagnetic waves have been intensively studied for many decades. Animal studies are carried out, but also data on human populations are collected and analyzed.
  - Despite a large number of high quality studies on the risk of cancer, especially of the brain, the head, and the neck as a result of increased exposure to electromagnetic fields, the risk increase has not been unequivocally confirmed.
  - Electromagnetic hypersensitivity can be a psychological phenomenon. This is confirmed by studies showing that the intensity of the symptoms is related to the subjectively perceived strength of the electromagnetic field rather than its actual strength.

II.1

Impact of the radio-frequency electromagnetic field on biological systems

Eugeniusz Rokita, Grzegorz Tatoń

In the environment around us, electromagnetic waves (EM) – i.e. electromagnetic field (EMF) disturbances propagating in space – occur naturally or are emitted using specially designed sources. EM wave sources (emitters) are characterized by huge dimensions range (the nucleus of an atom has the diameter of about 10^{-15} m, while the dimensions of radio transmitters are on the level of several meters). As a result, there are EM waves in nature that are both very short and very long. The full spectrum of EM wavelengths, commonly referred to as the EM wave spectrum, covers a number of ranges that have separate names, usually related to the way they are generated or detected (see article I.2. on page 14 and the infographics on page 38). Of note is the fact that the surface of the human body also emits EM waves, the maximum strength of which is for the wavelength of about 10 μm.

Propagation of EM waves is accompanied by transport of energy, which is easier to imagine if we treat these waves as a flow of particles – photons. Each photon has a specific energy, and the total energy of an EM wave is equal to the sum of the energies of the individual photons. The stream of photons is sometimes referred to as EM radiation. The basic unit used to express the energy of photons is eV – electron volt. Converted into the standard unit of energy used in physics, i.e. joule, $1\ eV \approx 1.6 \cdot 10^{-19}$ J. This shows that it is a very small unit, convenient for expressing energies observed in the micro-world.

A quick reminder: the energy of photons of visible light emitted e.g. by the Sun or an electrical bulb is in the range of 1.5 eV to 3.0 eV, while the energy of those emitted by the surface of the human body is equal to approx. 0.12 eV (as one can see, a cooler source emits photons with lower energy). The range of energy of the photons used in radiology is 20-160 keV. This book discusses mainly radio waves and microwaves in the 0.5 to 5.0 GHz frequency range, which corresponds to the photon energy of $2 \cdot 10^{-6}$ - $2 \cdot 10^{-5}$ and is about a million times smaller than the energy of waves constantly emitted by human skin.

Interaction of the electromagnetic field with matter

When describing the interaction of the EMF with any biological system, one must first calculate, based on Maxwell's equations (see article I.1. on page 8), the distribution of the EMF inside the object. Because the object of consideration is the interaction of the EM, this requires the knowledge of the parameters that characterize the electrical properties (specific conductivity, dielectric constant) and the magnetic properties (magnetic permeability) of this object. Then it is necessary to identify and quantitatively describe all physical effects that play a significant role in the energy transfer process. For most biological systems, the magnetic permeability is not much different from that of vacuum, which means that the interaction with the magnetic component of the EM wave is not meaningful and does not depend on the frequency of the external field used. As a result, it is possible e.g. to place a patient in a very strong field of a superconducting magnet for an magnetic resonance imaging (MRI) examination. It should also be emphasized that in the 0.5 to 5 GHz frequency range, biological substances are neither very good electrical conductors nor very good insulators.

For the human body, as early as at the stage of determination of the EMF distribution and calculations of the energy transmission, there are problems with precise determination of the geometry and the chemical composition – the human body is not a homogeneous metal plate for which the distribution of the field can be determined using a single formula. Furthermore, the body constantly responds to processes occurring in it, e.g. by dissipating the thermal energy supplied to it. From the medical point of view, the physical description of the electromagnetic field is not so important: the most important are the biological effects of the EMF, including possible diseases.

The problem with assessment of the biological effects is that the creation of a biological effect sometimes is not related in a simple way to the amount of energy transferred to the system. Suppose the solar radiation supplies 300 J to the surface of the body of a sunbathing man. The supply of a similar amount of energy in the form of X radiation with photon energy equal to 60 keV would most probably cause the death of a the person. For comparison, the energy of a small teaspoon of sugar (5 g) is equal to about 80 kJ. This fundamental difference in biological effects of identical values of supplied energy is related to different mechanisms of interference of the EM radiation with different wavelengths on the body. Solar radiation is practically entirely stopped by the skin and mainly causes a thermal effect: to put it simply, it heats up the skin. X radiation (i.e. radiation used in radiology) penetrates into the body and, furthermore, the energy of a single photon is so high that it is able to cause irreversible changes in the structure of chemical molecules, including the DNA, eventually leading to the death of the person.

The energy absorbed by the body is described quantitatively by way of determination of the so-called specific absorption rate (SAR). Mathematically, this parameter has quite a simple form: $SAR = c_w \Delta T/\Delta t$. In this formula, ΔT is the increase in temperature, and Δt is the time in which ΔT occurs. The cw coefficient is the specific heat of the tissue [J/ (kg · K)], i.e., informally speaking, a measure of how much heat can be deposited in a unit of mass of a given material.

The problem with determination of the SAR is more complex in the case of a human body than in the case of an inanimate object, because complex biological systems have the thermoregulatory ability. As a result, calculations of the SAR for a body must take into account a much larger number of parameters (blood perfusion, metabolism) than such calculations for material objects[1].

A separate issue is determination of the maximum amount of energy that can be supplied to a biological system without functional disturbances. For the human body, this means setting certain limits (standards) which, if exceeded, can be dangerous to health. In the case of EM radiation, this problem can be solved in two ways: indirect and direct. The indirect method consists in determination of the maximum power of the radiation that interferes with the system. The direct method consists in determination of the amount of energy absorbed by the system. The SAR coefficient corresponds to the power of the absorbed dose (dose absorbed in a unit of time) used in dosimetry of ionizing radiation.

Impact of the EMF on the human body

First of all, it should be recalled that the human body is a source of the EMF and produces energy through biochemical processes using

1 S. Kodera, J. Gomez-Tames, A. Hirata. "Temperature elevation in the human brain and skin with thermoregulation during exposure to RF energy." *Biomed Eng Online. BioMed Central*; 2018; 17: 1–17.

Internal (endogenous) electric fields in the body have strengths in the range of 10-100 V/m.

substances contained in beverages and food. The strength of the internal (endogenous) electric fields in the body is equal to 10-100 V/m (this and other units are discussed in article I.3. on page 22). In selected areas of the body (cell membranes), electric fields of much greater strengths can be observed. The human heart generates electrical potentials, the measurement of which on the skin surface is a commonly used diagnostic method (electrocardiography – ECG). On the other hand, measurement of variable currents flowing in nerve cells of the brain is the basis of electroencephalography (EEG).

The amount of energy needed to maintain basic physiological functions in the human body is referred to as basic metabolic rate (BMR). Hariss's and Benedict's empirical formulas are used to estimate the BMR. For a man aged 25 years with body weight of 70 kg and height of 180 cm, the BMR is equal to 1,760 kcal/d, which corresponds to an average power of 85 W (a large light bulb). The energy production in the human body fluctuates during the day and so does the body temperature. For a healthy person, daily temperature fluctuations of about 1°C are typical. The temperature is usually the lowest in the early morning and the highest in the early afternoon at about 5:00 PM.

A separate problem that needs to be taken into account when considering the impact of the EMF on the human body is the shielding ability of different biological structures. From the physiological point of view, when EM radiation reaches the surface of the skin, it strikes the boundary between two media of different electrical properties (conductivity, dielectric constant). A similar situation occurs at each boundary of two tissue structures. This results in various phenomena occurring at all boundaries of this type, as discussed in article I.3. on page 22.

Detailed calculations of the relationship of the EMF outside and inside any biological system are provided in academic biophysics textbooks[2]. It can e.g. be estimated that the electric field inside a cell is about five orders of magnitude (10^5) weaker than outside. The belief that such a weak outside EMF can affect the processes inside the cell seems unreasonable. On the other hand, the EMF inside the cell membrane is amplified.

Of note is also the fact that the parameters that characterize each biological system (temperature, concentration of substances, strengths of endogenous electric fields) are not constant in time. Deviations from the average values (noise) are a physiological phenomenon and do not cause any disturbance in the functioning of the body – thus, not every temporary increase in the strength of the electromagnetic field must be immediately harmful. To produce biological effects, the EMF must cause changes in parameters that exceed physiological fluctuations.

The last major issue related to the impact of the EMF on the human body is related to the fact that the body has mechanisms for recording very weak environmental signals. An example is the sense of sight. A person registers a flash of light when approximately 100 photons of EM radiation in the visible range reach outer surface of the eyeball (cornea). Assuming that the energy of a single photon is equal to 2.5 eV, it can be calculated that the total energy of the flash is $4.0 \cdot 10^{-17}$ J. This is an unimaginably small amount of energy that cannot be compared to any energy encountered in the macro world. The registration of such weak signals is possible because the retina of the human eye contains chemical compounds that respond with great sensitivity and selectivity to visible light. In addition to the eye, which responds to visible light, the human body has temperature-sensitive thermoreceptors (for cold and heat) located on the skin, which respond to infrared radiation. In addition to the aforementioned two types of receptors, humans have no other type of receptors that are able to detect the presence of EM radiation.

2 R.K. Hobie, B.J. Roth. "Intermediate Physics for Medicine and Biology." Springer, New York, 2007.

Myth:

The microwaves used in radio communications act like a microwave oven

In a microwave oven, the heating is caused by microwaves that excite vibrations of the water molecules in the heated product. The energy of the excited water molecules is then transferred to other molecules, which increases the temperature of the entire object. In order to excite water molecules, the frequency of the microwaves must be set properly – most often at 2.45 GHz. In addition to the appropriately set frequency, the electromagnetic wave must also have a sufficiently high power (exceeding 1,000 W) to effectively heat the substance when it enters it. Mobile telephony base stations do not use the frequency of 2.45 GHz, which is in the 2.4-2.4835 GHz band intended for industrial, scientific, and medical purposes. Devices operating at this frequency range include devices with a WiFi or Bluetooth interface; however, the power of their transmitters is very small compared to the power of a microwave oven. For example, the typical power of devices with a Bluetooth interface is approx. 0.001 W – a million times less than that of a typical microwave oven. Consequently, these devices are completely safe and, even if used on a daily basis, do not lead to dangerous heating of tissues.

Absorption of electromagnetic energy in the human body

In the simplest terms, the interaction of EM radiation with any object can be described using the absorption law. Absorption properties of a medium are sometimes characterized by the so-called penetration depth δ (delta). It is defined so that at an absorber thickness δ, the power density (intensity) is reduced to 13.5% of the original value. For example, the depth of muscle tissue penetration by radiation with the frequency of 2.45 GHz (microwave oven) is equal to 1.67 cm. This means that only 13.5%, or about 1/7th, of the original EMF power remains at the depth of 1.67 cm below the surface of the tissue and only the rest penetrates deeper into the body. Most of the energy (86.5%, or about 6/7th) is absorbed by the muscle.

It should be noted that the heat generation rate in the tissue is inversely proportional to the

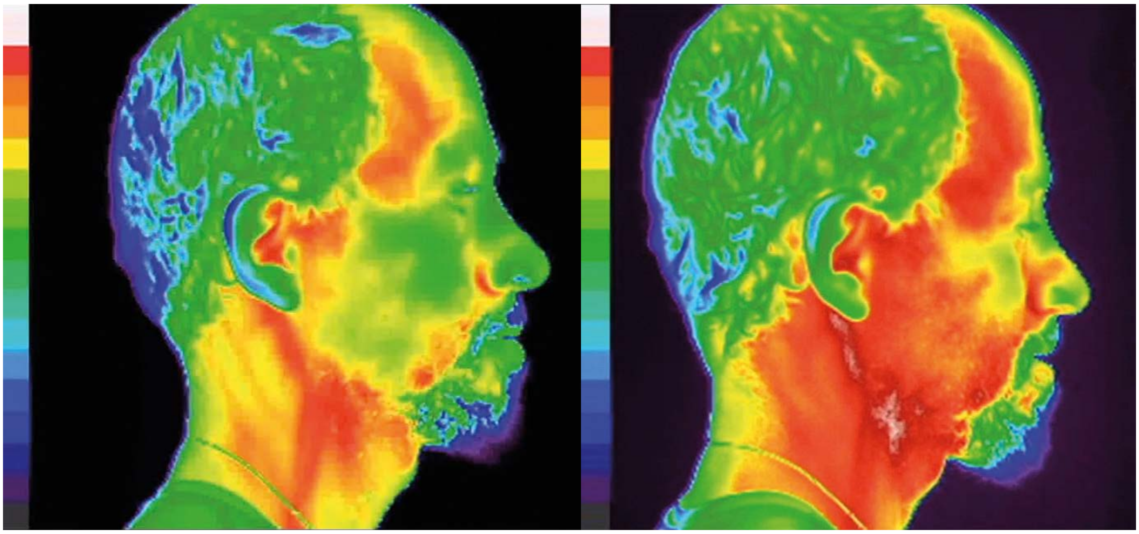


Fig. 1. The thermal effect, i.e. heating of tissues, is the best studied effect of use of mobile phones. The two photos shown above were taken using a thermal imaging camera that captures infrared radiation, which shows the temperature of tissues: the colors in the upper part of the scale correspond to higher temperatures. The picture on the right shows the effects of a 15-minute phone call, during which the phone was held directly at the body. The effect would be similar if any warm object was held in the same place. Tissue heating is temporary and does not cause any long-term harmful medical effects, and the body temperature soon return to normal (picture on the let).

square of the penetration depth.Consequently, tissue of low penetration depth, due to high water content (e.g. muscle tissue), heats up faster as a result of exposure to the EMF than tissue with a high depth of penetration due to low water content (for example, for fat tissue the factor δ is equal to 8.1 cm at 2.45 GHz). As a result, the heat up speed of muscle tissue is about 25 times higher than that of fat tissue.

Currently a more advanced approach is used to quantify the impact of EM radiation on any object. First, the EMF distribution inside the object is calculated, followed by the SAR coefficient distribution. The final step of the calculation is to calculate the temperature distribution, with the SAR being treated as an additional energy source. For the human body, calculation of temperature distribution requires consideration of the mechanisms of heat loss and heat transport. Commercially available software us used for the calculations.

Thermal effects

The biological effects of the EMF related, directly or indirectly, to temperature increases are referred to as thermal effects. The effects occurring when possible biological effects cannot be linked to tissue heating are referred to as non-thermal effects.

It can be estimated that if the human body does not release heat, the body temperature rises at the speed of approx. 1.2°C/h. Thus, after about 4 hours, the person would die of a deadly fever. In reality, an increase in body temperature activates the body's heat transfer mechanisms. When considering the heating of a human body as a result of the EMF, one must remember about physiological facts.

In the human body there are heat transport mechanisms that compensate for local temperature rises. It should be noted that the EMF produces a heterogeneous temperature distribution in tissues. The absorption effects are most intense in the surface layers. The final temperature of the tissue is a function of the amount of energy deposited by the EMF and the intensity of blood flow and thermal

Although theoretically an increase in temperature may have many indirect effects in the human body, there is no evidence for this in practice.

conductivity of the tissue. It should be clearly emphasized that the effect of hyperthermia caused by exposure of the body to the EMF is the only effect that can be quantified on the basis of physical considerations.

Although theoretically an increase in temperature may have many indirect effects in the human body, there is no evidence for this in practice. In the scientific literature there are theses that higher temperatures can change the speed of biochemical reactions. An increase in temperature may also be associated with a change in protein synthesis and protein binding to the cell membrane. It is well documented that every cell responds to an increased temperature by producing so-called *heat shock proteins (HSP)*. An increase in temperature also changes the values of many important parameters from the point of view of homeostasis of the entire biological system. Viscosity of body fluids, solubility of gases in body fluids, specific heat of tissues, diffusion coefficients, and electrical conductivity of tissues are examples of parameters which depend on temperature. These changes can also be observed when the temperature of the body is raised due to physical effort.

We know about the impact of these factors on the functioning of the human body from theoretical analyses, as well as from laboratory experiments. Despite the huge number of studies on the subject, it is even difficult to show whether an increase in temperature caused by exposure to an electromagnetic field with strength typical of telecommunications applications has any significant effects on the human body. Most likely, small (up to 2-3°C) local temperature increases caused by exposure to the EMF are compensated in the body by thermoregulation mechanisms. These are values that only slightly exceed the physiological body temperature fluctuations: the changes in body temperature are much greater during a daily bath.

Non-thermal effects

Purely hypothetically, the EMF can cause a whole range of effects, even with slight temperature increases. In order to clearly define a given effect as thermal or non-thermal, a limit value of temperature increase (ΔT) should be specified, below which the effect is classified as non-thermal. Normally, it is assumed that $\Delta T = 1°C$.

It should be strongly emphasized that the frequency range of EM radiation considered in this book is characterized by too low energy of photons to cause ionization or destruction of chemical bonds. As we remember, the energy of the photons of radiation used in telecommunication is on the level of 10^{-6} eV, i.e. one million electronvolts. For comparison: the energy of a typical chemical bond is on the level several eV. For example, in order to break the O-H bond, which is present for example in a water molecule, one needs to supply around 5.15 eV. Even the energy of much weaker bonds, so-called van der Waals bonds, which help to maintain the shape of large particles present in living cells (biomolecules), e.g. proteins, is equal to 0.08-0.4 eV.

Chemical molecules can also be stimulated in a more subtle way, without destroying their bonds, by inducing them to vibrate or rotate. However, this is unlikely to be the case for radio-frequency EMF. To induce the rotational states of a two-atom molecule, EM radiation with the frequency higher than 30 GHz must be used. In order to induce vibrations of two-atom molecules, the energy of 0.04 eV (IR range) is required. Typical vibration frequencies in a system with hydrogen bonds are on the level of 300 GHz, two orders of magnitude greater than the EMF range under consideration. The numbers provided clearly prove that the EMF in the frequency range specified above, due to too low energy of photons, is not able to cause changes in the structure or excitation of biomolecules.

Thus, if non-thermal interaction of the EMF with biological systems exists, it can only consist in

Myth:

Radiation associated with mobile phones is as dangerous as that associated with radioactivity

The basic difference between the electromagnetic radiation used in mobile telephony and the radiation emitted by radioisotopes or produced in an X-ray tube lies in the energy of photons. In the former case, it is in the range of $2 \cdot 10^{-6} – 2 \cdot 10^{-5}$ eV, while in the latter case it is billions of times higher (X-ray tube: 20-160 keV; ^{60}Co isotope used in radiotherapy: 1.17 MeV and 1,33 MeV). Consequently, the radiation of a telephone is very strongly absorbed by the surface layers of the human body, while the radiation associated with radioactivity penetrates into the body without any obstacles. Once it enters the human body, the radiation produced by a telephone can only cause thermal effects (slight heating of tissues) because the photon energy is too low to excite or destroy biomolecules. Radiation associated with radioactivity (ionizing radiation) is characterized by sufficient energy of photons to destroy the structure of biomolecules (e.g. to break both DNA strands), which causes many negative effects in the body.

occurrence of complex effects. Their proposals were created based on theoretical considerations or laboratory experiments. The list of possible complex effects was finalized around ten years ago[3]. Since then, no recognized evidence for their existence has been presented, although the search for non-thermal effects that occur during interaction of the EMF with the human body is the subject of research conducted in many laboratories. Currently, research focuses on two types of issues. The first concerns potential medical effects, i.e. effects on the macro scale, which can be recognized by different diagnostic methods. These studies concern selected organs or certain aspects of the functioning of the entire biological system. The results are ambiguous, which automatically translates into different interpretations. For some authors, the results prove the harmful effects of the EMF on the human body, while others believe that the conclusions related to harmfulness of the EMF

3 A.R. Sheppard, M.L. Swicord, Q. Balzano. "Quantitative evaluations of mechanisms of radiofrequency interactions with biological molecules and processes." *Health Phys*. 2008; 95: 365–96.

are over-interpretations and that the issue requires further investigation[4]. The second type of research is experiments on animals, the results of which are extrapolated to the human body. This approach has obvious limitations, especially when small laboratory animals are used.

Conclusions

So far, no single universally accepted theory has been to describe the operation of the EMF with in the 0.5-5 GHz frequency range on the human body. The results of the experiments are interpreted on the basis of different biophysical models. It should be emphasized that this frequency range of the EMF is currently widely used in various fields of science and technology (telecommunications, radiolocation, satellite navigation, medicine, radio astronomy, and microwave heating). The effects caused in the human body are correlated with the power density of the EMF. The effects associated with high-power EMF applications occurring in microwave ovens are universally known. Locally acting high power densities of the EMF are used therapeutically in medicine, for example to destroy neoplastic lesions (*NanoKnife* technique).

It is known that the EMF induces thermal effects in the human body. The EMF power streams present in the environment generate additional energy sources in organisms that cause their temperature to rise. The energy transmitted by the EMF represents a small percentage of the energy generated in an organism as a result of the basic metabolic rate and it is difficult to believe that it can cause pathologies. In the human body there are thermoregulation mechanisms that function on a daily basis life by compensating for much bigger changes of temperature.

A separate, so far unsolved problem is that the EMF in the human body induces non-thermal effects, both short- and long-term. Interaction through physical processes is rather impossible – a single photon of a radio wave does not have enough energy to, for example, break the chemical bond. At the most, one can consider more subtle complex effects. However, the extensive literature on the subject does not provide a clear answer as to whether this kind of effects occur in the human body at all.

Any physico-chemical agent acting on the body, depending on the doses used (concentration, intensity, flux), can cause both negative and positive effects on the body (hormesis effect). An example is solar radiation. Too much of it causes pathological skin lesions. However, humans cannot exist in an environment devoid of this radiation. It is possible to determine a certain range of intensity of solar radiation that is optimal for the functioning of the human body. Most likely the hormesis effect also occurs for other EMF ranges.

The standards applicable in different countries, including, of course, Poland, are aimed at defining a safe range, also for the EMF used in telecommunication (see the articles in section III, from page 71 onwards).

4 Cf.: M.L. Pall. "Wi-Fi is an important threat to human health." *Environ Res*. 2018; 164: 405–16. T. Saliev, D. Begimbetova, A.R. Masoud, B. Matkarimov. "Biological effects of non-ionizing electromagnetic fields: Two sides of a coin." *Prog Biophys Mol Biol*. 2019; 141: 25–36.

II.2
Impact of microwaves and radio-frequency waves on humans

Grzegorz Tatoń, Eugeniusz Rokita

Introduction

Research on the effects of electromagnetic radiation (EMF) on health is extremely difficult. The main reason for this is that, for ethical reasons, it is not possible to expose people to the tested agents in controlled conditions in the full power range and in the appropriate time scale. Even though one can imagine experiments with the participation of people in the case of high field strengths leading to the observation of thermal effects occurring almost immediately, testing of non-thermal effects is practically impossible in controlled conditions (the difference between thermal effects and non-thermal effects is described in article II.1. on page 50). The expected health effects of non-thermal interactions are subtle and if they really happen, they manifest themselves on a very long time scale. Keeping an investigated population in controlled conditions over a period of up to twenty years is impossible.

In this situation, conclusions about positive or negative impact of EMF can only be based on experiments on animals, on so-called cell cultures (isolated cells), or on population studies. Each of these solutions has limitations and significant shortcomings. In the case of experiments on animals, it is not obvious whether the results can be transferred directly to humans, due to significant differences between different organisms. The conclusions from research on cell cultures can also raise doubts due to the fact that cell behavior is different in culture conditions than in an organism. For example, cells in cultures are not secured by complex defense mechanisms. The results of population studies are burdened with errors related to the fact that it is not possible to reliably control EMF exposure in the surveyed population of people and to eliminate the impact of thousands of other environmental factors.

For these and other reasons, the results of research on the health effects of the EMF are in many cases contradictory. At this point in time, the negative or positive impact of the EMF on humans cannot be clearly confirmed and in the scientific community there are large differences in the conclusions drawn from results of research conducted in this field[1].

The primary source of the EMF with potential negative health effects on a significant part of the population are emissions associated with wireless telecommunications. During a phone call using a wireless or mobile phone, the head area is subject to the greatest exposure to the field. Many scientists study the possibility of harmful effects of the EMF on the central nervous system. A particularly vulnerable

1 S.A.R. Mortazavi, A. Tavakkoli-Golpayegani, M. Haghani, S.M.J. Mortazavi. "Looking at the other side of the coin: the search for possible biopositive cognitive effects of the exposure to 900 MHz GSM mobile phone radiofrequency radiation." *J. Environ. Heal. Sci. Eng.* 2014; 12: 75.

part of the body seems to be the brain, but also the auditory nerve and the optic nerve, the thyroid gland, the salivary glands, and the eyes.

Research is also being conducted on the influence of the EMF on other systems, tissues, and processes taking place in the human body, e.g. the cardiovascular, hematopoietic, immune, and reproductive systems. The effect of the EMF on the circadian rhythm, the healing processes, and the hormonal and gene balance is being analyzed. Scientific literature on this topic is very extensive and diverse. It is impossible to take into account all the postulated effects of electromagnetic fields in such a short document. For this reason, the document will briefly discuss the issues that seem to be most frequently addressed, i.e. cancer, electromagnetic hypersensitivity, impairment of nervous system functions, and threats to the reproductive system.

Before we discuss the potential negative health effects of microwaves and radio waves, it should be noted that electromagnetic fields of different frequencies are used for diagnostic and therapeutic purposes. The methods used are generally considered to be completely safe for the patient. The most commonly known example is magnetic resonance imaging, where the imaging is possible due to the use of radio-frequency electromagnetic waves. New diagnostic and therapeutic methods based on the EMF are constantly being tested and introduced. An example of diagnostic applications is microwave imaging of breast cancer and an example of therapeutic applications is support of treatment processes in bone diseases.

Cancer

Despite extensive epidemiological studies, there has been no evidence of increased risk of brain, head, or neck cancer due to increased exposure to EMF.

This is related to the above-mentioned difficulties in interpretation of research results[2], and the

2 IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, World Health Organization, International Agency for Research on Cancer. "Non-ionizing radiation. Part 2, Radiofrequency electromagnetic fields."

Selected organizations dealing with the impact of the EMF on human health

WHO – World Health Organization
A specialized agency of the United Nations responsible for international public health. One of the problems that the WHO works on is the impact of environmental factors on human health, including the impact of the EMF.

IARC – International Agency for Research on Cancer
An agency of the WHO that coordinates international cancer research. The IARC deals, among other things, with the classification of environmental factors according to the likelihood of their carcinogenic effect on humans. The IARC has classified the EMF in the radio frequency range as a possible carcinogen, but scientific evidence of their carcinogenic nature was not considered sufficient.

ICNIRP – International Commission on Non-Ionizing Radiation Protection
The ICNIRP is an organization of independent scientists dedicated to the study of the possible effects on human health caused by exposure to non-ionizing radiation. The activities of the ICNIRP includes issuing of recommendations suggesting EMF strength levels that ensure safe use of technologies based on EMF applications.

Myth: The IARC has identified radio-frequency radiation as a carcinogenic agent

"In 2011, the IARC classified the radio-frequency electromagnetic field to Group 2B of carcinogens." This statement appears very often in scientific publications, but also in mass media and is presented to the public without any explanation or comments. This leads to a lot of misunderstanding and causes unnecessary anxiety. For people without professional knowledge, the message seems obvious: "The EMF causes cancer." But it is not that simple.

Let us start by listing other, better-known agents, also classified by the IARC to group 2B. There are currently 311 such factors and they include aloe vera leaves extract, coffee acid, chloroform, diesel oil, implanted foreign bodies containing metallic nickel (e.g. earrings), naphthalene, pickled vegetables, and talcum-based body powder. Everyone has dealt or is dealing with most of these agents on a daily basis.

Let us briefly explain what the IARC classification of carcinogens is. These agents were divided into five groups:

- group 1: carcinogenic to humans;
- group 2A: probably carcinogenic to humans;
- group 2B: possibly carcinogenic to humans;
- group 3: not classifiable as to its carcinogenicity to humans; and
- group 4: probably non-carcinogenic to humans.

The misunderstanding results from the difficulty in translating the two English words used in the definitions of group 2A and 2B. It can be assumed that in English "possibly" means rather low likelihood, while "probably" means rather high likelihood. The definition of group 2B could therefore be translated differently: "group 2B: agents that are unlikely to be carcinogenic." The specific definition of group 2B is the following: "Category 2B – This category is used for agents for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity in experimental animals […] An agent may be classified in this category solely on the basis of strong evidence from mechanistic and other relevant data[3]. "Mechanistic relevant data" are data that result directly from the laws of basic sciences, such as physics, chemistry, biology, etc. In short, the carcinogenic effect of the EMF cannot be ***excluded*** due to basic laws of physics, chemistry, and biology (because we do not know all laws governing the world), but there is no convincing scientific evidence confirming an ***actual*** carcinogenic nature of this radiation.

relationship between thyroid cancer and exposure to the EMF is a great example of how crucial is the elimination of relevant environmental factors other than the EMF. Researchers have analyzed the increase in thyroid cancer incidence in the years 1970-2013 in Sweden. In the analyzed period, the exposure to the EMF has increased significantly as did the incidence of thyroid cancer. However, such a statistical link (correlation) does not mean that there is a causal link. As it turns out, exposure to ionizing radiation has also increased significantly in the same period. This happened because of the higher availability of diagnostic methods utilizing ionizing radiation (e.g. computed tomography and dental radiography). It is common knowledge that the incidence of thyroid cancer is closely related to exposure to ionizing radiation.

3 Ibid.

There is one more, quite unintuitive effect that must be taken into account. Interestingly, the higher incidence of diseases may result from technological progress in medicine.On the one hand, an improvement in the quality of healthcare leads to an increase in average life expectancy – most cancers occur in elderly people. On the other hand, however, more effective diagnostics means that these diseases are simply diagnosed more frequently. In the past, people would die for unknown reasons and today the majority of deaths can be attributed to specific diseases, e.g. thyroid cancer. Unfortunately, there is no easy way to estimate the significance of such factors.

In recent years, numerous experiments have been conducted to provide evidence for the carcinogenic nature of exposure to the EMF. Particularly high hopes for an unambiguous answer were put in two large-scale long-term experiments. Although they do not directly concern effects in humans, as they were carried out on animals, they are worth mentioning here.

One of the projects involved an experiment on the long-term effect of exposure to the EMF on rats, which has been conducted since 2005 by the Bernadino Ramazzini Institute[4]. A second project is the study of the effect of radiation emitted by mobile telephony devices, also using animal models (mice and rats), conducted under the U.S. National Toxicology Program (NTP). The NTP is a program intended to identify environmental threats to human health. In 2016, a preliminary report on the course and the results of the NTP project was published.

Both experiments involved very numerous groups of animals (Ramazzini – about 2,500, NTP – about 360). The tests were performed with electromagnetic radiation with the frequencies used in mobile telecommunication. The highest power densities used exceeded those that are used in practice and can be encountered in the environment. Animals were exposed to the field for a significant part of the day (Ramazzini – 19 hours, NTP – 18 hours) and throughout their whole lives, starting from conception. The morbidity of the animals exposed to the radiation with regard to cancer was analyzed and the results were compared with control groups. In both experiments, the researchers observed an increase in the frequency of some rare neoplastic lesions, Schwann cell tumor of the heart and brain glioma.

Unfortunately, in the case of both research projects, the results and especially their interpretation may raise some doubts. For example, in the experiments, no cases of the analyzed types of cancer were often observed in the control groups (although the historical data available to the Ramazzini Institute and to the NTP indicated that they were to be expected). Consequently, even a small proportion of diseases in the groups exposed to the field, compared to the control group, where there were no cases at all, constitutes a significant increase. Also, in some cases, in the group exposed to a strong field there was lower morbidity than in the control group. Moreover, in the NTP experiment, the control group has a lower survival rate than the group of animals exposed to the field, which may suggest that the field increases the average life expectancy. The authors are aware of the fact that their results are not very convincing, but conclude that their evidence should lead the IARC to verify the classification of EMF.

Critical evaluation of the results of both experiments will most probably not lead to a change in the assignment of the EMF to a different group of carcinogens than now. This is the position of the ICNIRP expressed in the document published in 2018[5]. The document contains a detailed explanation as to why the results of the research by the NTP and the Ramazzini Institute cannot be used as a basis for revising the recommendations concerning the exposure limit values for electromagnetic radiation in the radio frequency range. Numerous methodological errors made in both studies were indicated and attention was brought to the inconsistency in the results obtained by both groups.

4 "ICNIRP Note on Recent Animal Carcinogenesis Studies," Munich, Germany. 2018; September: 1–8.

5 Ibid.

Results of some research may suggest that exposure to the EMF increases the risk of cancers and, in combination with exposure to other known carcinogens, accelerates their growth. It cannot be excluded that it is the thermal effects that in this case are the main or sole biological mechanism. Since no mechanisms of direct, non-thermal impact of the EMF on the development of cancer are known and confirmed, this relationship can be put in question[6]. As a result, the WHO is of the opinion that, in the case of mechanisms of the impact of the EMF on humans, all health effects associated with it, including cancer, are a consequence of temperature increase. Since the mechanisms of the thermal impact are known and their effects are easily measurable, they can be used as a basis for the determination of safe standards for EMF strength levels.

Electromagnetic hypersensitivity

Electromagnetic hypersensitivity (EHS, sometimes also referred to as "electrosensitivity") is considered to be an idiopathic condition, i.e. one whose causes are unknown and which is caused by undefined factors. EHS is associated with a whole range of non-specific symptoms that are sometimes difficult to assess objectively, e.g. increased fatigue, weakness, headache, tinnitus, insomnia, memory disorders, pain in various parts of the body, heart dysfunctions, feelings of warmth, nausea, dizziness, etc.[7] People reporting symptoms related to the impact of electromagnetic field are often referred to in the professional literature as "persons self-describing as hypersensitive."[8].

Many publications have shown no correlation between symptoms reported by hypersensitive persons and actual exposure to electromagnetic fields[9].

There are no undeniably proven mechanisms of direct, non-thermal impact of microwaves on the development of cancer.

For example, in one research,[10] it was found that the occurrence of symptoms associated with EHS in mobile phone users is not more frequent. It appears that knowledge of the subjects about the use of the field influences the results of such studies. For this reason, in provocation tests (in which the reaction of the subjects to the EMF is checked), the double-blind test method should be used.

In this research method, neither the participant nor the person conducting the experiment knows whether the investigated factor has been applied or not. As a result, there is no element of autosuggestion (i.e. a situation where the participant expects negative effects, which by itself can cause them) or suggestions from the person conducting the experiment (even if the participant does not know whether in a given case the EMF is present or not, the person conducting the experiment can – intentionally or not – pass this information to the participant).

This method seems particularly important for research on the EHS. A kind of summary of this problem is the so-called meta-analysis of seventeen studies on the health effects of the electromagnetic field emitted by mobile base stations[11]. The differences between the results of the studies performed using the double-blind method and the results of the studies where the participants were informed about the presence of a field were analyzed. When

6 A. Schoeni, K. Roser, M. Röösli. "Symptoms and the use of wireless communication devices: A prospective cohort study in Swiss adolescents." *Environ. Res.* 2017; 154: 275–283.

7 M.J. Gruber, E. Palmquist, S. Nordin. "Characteristics of perceived electromagnetic hypersensitivity in the general population." *Scand. J. Psychol.* 2018; 59(4): 422–427.

8 Mortazavi et al., op. cit.; Gruber et al., op. cit.

9 Mortazavi et al., op. cit.; C. Boehmert, A. Verrender, M. Pauli, P. Wiedemann. "Does precautionary information about electromagnetic fields trigger nocebo responses? An experimental risk communication study." *Environ. Heal. A Glob. Access Sci. Source*. 2018; 17(1): 1–15; A. Klaps, I. Ponocny, R. Winker, M. Kundi, F. Auersperg, A. Barth. "Mobile phone base stations and well-being – A meta-analysis." *Sci. Total Environ.* 2016; 544: 24–30.

10 Mortazavi et al., op. cit.

11 Klaps et al., op. cit.

In the case of experiments on animals, it is not obvious, due to significant differences between different organisms, whether the results can be transferred directly to humans.

the participants knew they were exposed to the EMF, the symptoms appeared more often, but when the samples were double-blind, there was no connection between the EMF exposure and the symptoms. In short, the negative effects on their well-being were more likely to appear when the participants expected them and not when the participants were actually exposed to the EMF. This suggests that at least some of the observed effects can be explained by psychological factors but, at the same time, it puts in question the real physical impact of the EMF on the well-being of the participants.

An extensive epidemiological study on the EHS, completed in 2015, covered nearly 6,000 participants[12]. The purpose of the project was to determine the relationship between exposure to electromagnetic fields, the quality of sleep and the EHS. An analysis of the data of hypersensitive patients contained in their official medical records showed no significant correlation between exposure and observed health effects. The results suggest that occurrence of EHS depends on the perception of the risk of exposure to the EMF. It was also shown that the exposure perceived by the participants had nothing to do with the actual exposure: the participants could not realistically assess the strength of the EMF in their place of residence. This clearly suggests the involement of psychological factors in the case of the EHS. Such conclusions are consistent with the image based on a review of the literature. There seems to be no relationship between the subjectively determined well-being and the exposure to the EMF, whether or not the subjects consider themselves affected by the EHS. Furthermore, there is no confirmation that electrosensitive people are able to feel the presence of the electromagnetic field.

Efforts are being made to investigate how common the EHS is. The scale of this phenomenon can be determined on the basis of experience of healthcare professionals who are in contact in their work with hypersensitive persons. It is estimated that 68-75% of such people in Europe have encountered patients who associate their symptoms with the impact of the EMF. For example, the results of surveys carried out among Dutch hygienists and doctors indicated that about 1 in 3 had dealt with the EHS in their work. Many of the respondents believed to some extent that there was a cause and effect relationship between the symptoms reported by patients and their exposure to the electromagnetic field and for this reason they sometimes recommended exposure reduction to the patient. Consequently, sometimes patients hear from their doctors that the electromagnetic field can actually be responsible for their condition.

Population studies make it possible to determine the prevalence of EHS, but also to define the profile of electrosensitive people[13]. People who complain about EHS are most often middle-aged women who describe their health as not being the best. Electrosensitivity is usually a consequence of a single exposure to a field with high power density or of long-term exposure. Such conclusions were drawn after conducting randomly selected surveys of people: 91 out of 3,341 respondents described themselves as electrosensitive. This may suggest that about 3% of the population associates deteriorated well-being with the impact of the EMF.

In the absence of reliable evidence of non-thermal effects of the EMF at the physical level, it

12 C. Baliatsas, J. Bolte, J. Yzermans, G. Kelfkens, M. Hooiveld, E. Lebret, I. van Kamp. "Actual and perceived exposure to electromagnetic fields and non-specific physical symptoms: an epidemiological study based on self-reported data and electronic medical records." *Int. J. Hyg. Environ. Health*. 2015; 218(3): 331–44.

13 Gruber et al., op. cit.

appears that biological effects are not to be expected either. However, the human body is such a complex system that biological effects can occur without the presence of a physical stimulus. The placebo and nocebo effects are well-known and broadly described in medicine. They are based on the fact that a suggestion of a positive (placebo) or negative (nocebo) influence of a physicochemical factor through the influence on the psyche can cause health effects.

The nocebo effect is one of the suggested hypotheses explaining the impact of the electromagnetic field on humans. If the nocebo effect that is responsible for the occurrence of, among others, the EHS, it is easy to come to the conclusion that an appropriate and reliable way of informing about the hazards associated with exposure to the field, or lack thereof, is the key to the fight against this disease. On the other hand, providing incorrect information and maintaining a sense of hazard can cause specific health damages in many people.

Research on the nocebo effect in the context of the EMF shows that even the recommendations for caution in use of wireless communication devices (often enforced by regulations) can inspire in an average person the belief that it is dangerous to use this type of technology. It has been shown, for example, that the number and intensity of observed symptoms are more closely related to the parameters that describe the use of a mobile phone (e.g. number of sent and SMS text messages) than to the actual measured exposure to the field emited by these devices[14]. In other words, the symptoms of electrosensitivity have more to do with the subjective belief about the intensity of use of a mobile phone than with the actual strength of the EM radiation. This study shows that there is no connection between the symptoms and the real exposure – the very feeling of threat causes the problem.

This is confirmed by the results published by Dutch scientists who, in addition to the impact of the EMF, considered other harmful environmental factors.[15] When the factor is easy to observe – like air pollution and noise – the participants of the study assessed the actual exposure much better. The negative symptoms in the participants had a closer relationship to actual air pollution and noise – while there was no such relationship in the case of the impact of the EMF, which, as you know, we are not able to register with our senses.

Impact on the nervous system

In addition to the risk of cancer of the nervous system caused by exposure to the EMF, there is a wide range of nervous system disorders that are attributed to the impact of this type of waves. These include sleep disorders and insomnia, headaches, depression symptoms and depression, fatigue, sensory disturbance, attention deficit, cognitive function and memory disorders, irritability and hyperactivity, loss of appetite, anxiety, fear, nausea, dizziness, skin itching, and changes in EEG results. Except for the last of the listed symptoms, most of them are subjective and coincide with the non-specific symptoms also reported by people with the EHS.

The brain is especially intensively investigated for this purpose for at least two reasons. First, the mobile phone is held during a call at the head and, consequently, the thermal effects will, of course, be present in this part of the body. Second, there are several hypotheses about non-thermal effects, which could be of great importance in the case of the brain. Potential adverse effects on the central nervous system may be associated with increased permeability of the blood-brain barrier, loss of neurons and glial cells, and disturbances in the functioning of neurotransmitters[16]. However, this has not been confirmed.

One of the most frequently postulated biochemical mechanisms of the impact of the EMF on

14 Schoeni et al., op. cit.

15 A.L. Martens, M. Reedijk, T. Smid, A. Huss, D. Timmermans, M. Strak, W. Swart, V. Lenters, H. Kromhout, R. Verheij, P. Slottje, R.C.H. Vermeulen. "Modeled and perceived RF-EMF, noise and air pollution and symptoms in a population cohort. Is perception key in predicting symptoms?" *Sci. Total Environ.* 2018; 639: 75–83.

16 Mortazavi et al., op. cit.; B.Z. Altunkaynak, G. Altun, A. Yahyazadeh, A.A. Kaplan, O.G. Deniz, A.P. Türkmen, M.E. Önger, S. Kaplan. "Different methods for evaluating the effects of microwave radiation exposure on the nervous system." *J. Chem. Neuroanat.* 2015; 75: 62–69.

the human body is oxidative stress. This mechanism is described mainly in relation to the central nervous system, because it can lead to neurodegeneration[17]. If the EMF was really associated with the occurrence of oxidative shock, this would be a strong argument for the relationship between exposure and the risk of developing severe central nervous system disorders, such as cancer, Alzheimer's disease, and Parkinson's disease[18]. No evidence of this has been found so far.

The second most frequently postulated mechanism of impact of the electromagnetic field on the body is the disturbance in functioning of the calcium channels. These channels are located in cellular membranes and make it possible to maintain ionic balance in cells. Another element related to the functioning of the nervous system is synapses. It is believed that learning and memory impairment can be caused by a disorder in the functioning of synapses. Results of research have been published, in which such effects were found after exposure to the electromagnetic field[19]. However, many scientists put them in question.

As with other aspects of the health impact of the EMF, in the case of the nervous system, the results of the studies are also contradictory. Two groups of Korean scientists conducted research on the impact of a field from the frequency ranges used in mobile telephony on mice[20]. While many negative effects were observed in one project, no such effects were found in the other. One group described the hyperactivity of the examined animals and the other did not find any behavioral or memory disorders and even suggested a beneficial field effect of the field in some neurodegenerative diseases.

The symptoms of electrosensitivity have more to do with the subjective belief about the intensity of use of a mobile phone than with the actual strength of the radiation. It is the very sense of threat that causes ailments.

Impact on the reproductive system

The reproductive system is very sensitive to environmental factors, and the consequences of its malfunction may have an adverse effect on fertility. Because, due to changes in the design and functionality of mobile devices, they are worn near the body for many hours a day and, furthermore, they fit in trouser pockets, the exposure of the gonads has increased significantly. For this reason, the question concerning potential problems with fertility that may be associated with impact of the EMF is most justified.

The best summary of the research on the impact of EMF on the reproductive system is provided by two meta-analyses of available reports on its impact on sperm quality[21]. It was found that exposure to the field emitted by a mobile phone has a negative impact on sperm motility and life span, but does not decrease their number[22], but the authors link the observed decrease in semen quality

17 Ibid.

18 Mortazavi et al., op. cit.

19 Altunkaynak et al, op. cit.

20 J.H. Kim, D.H. Yu, Y.H. Huh, E.H. Lee, H.G. Kim, H.R. Kim. "Long-term exposure to 835 MHz RF-EMF induces hyperactivity, autophagy and demyelination in the cortical neurons of mice." *Sci. Rep.* 2017; 7: 1–12; Y. Son, Y.J. Jeong, J.H. Kwon, H. Do Choi, J.K. Pack, N. Kim, Y.S. Lee, H.J. Lee. "1950 MHz radiofrequency electromagnetic fields do not aggravate memory deficits in 5xFAD mice." *Bioelectromagnetics*. 2016; 37(6): 391–399.

21 J.A. Adams, T.S. Galloway, D. Mondal, S.C. Esteves, F. Mathews. "Effect of mobile telephones on sperm quality: A systematic review and meta-analysis." *Environ. Int.* 2014; 70: 106–112; K. Liu, Y. Li, G. Zhang, J. Liu, J. Cao, L. Ao, S. Zhang. "Association between mobile phone use and semen quality: A systemic review and meta-analysis." *Andrology*. 2014; 2(4): 491–501.

22 Adams et al., op. cit.

with an increase in the temperature of the testicles. The researchers believe, however, that the increase in temperature is caused by a heating telephone and does not result from the direct effect of the EMF on tissues.

Conclusions

As this chapter indicates, there are large differences of opinion in the scientific community about the impact of the EMF on the human body. In many cases, the available research results are contradictory. The negative impact of exposure to this type of radiation on the human body cannot be clearly confirmed.

Considering the potential risk of negative impact of the EMF, it would seem reasonable to formulate a principle similar to the ALARA principle, which is used in the case of ionizing radiation. The ALARA (*As Low As Reasonably Achievable*) principle states that unnecessary exposure should be avoided. This is easy in the case of ionizing radiation, because there are not too many artificial sources of such radiation in the environment. In the case of electromagnetic radiation, it would require switching off all its sources, that is practically all electrical communication devices. which is obviously impossible, if not absurd.

It is therefore necessary to determine the civilization costs, but also the health costs of such an operation compared to the risk, which is not fully confirmed, as is the case with ionizing radiation.

Moreover, one must also consider the fact that sometimes even scientific publications present biased interpretation of the results or results of experiments carried out using inappropriate methodology. Based on biased works, it is possible to prove the negative effects of radio waves on the human body, which, combined with the low level of knowledge of the general public about such effects, may lead to serious and negative consequences to the public.

KEY AREAS OF HEALTH EFFECTS OF MICROWAVES AND RADIO WAVES

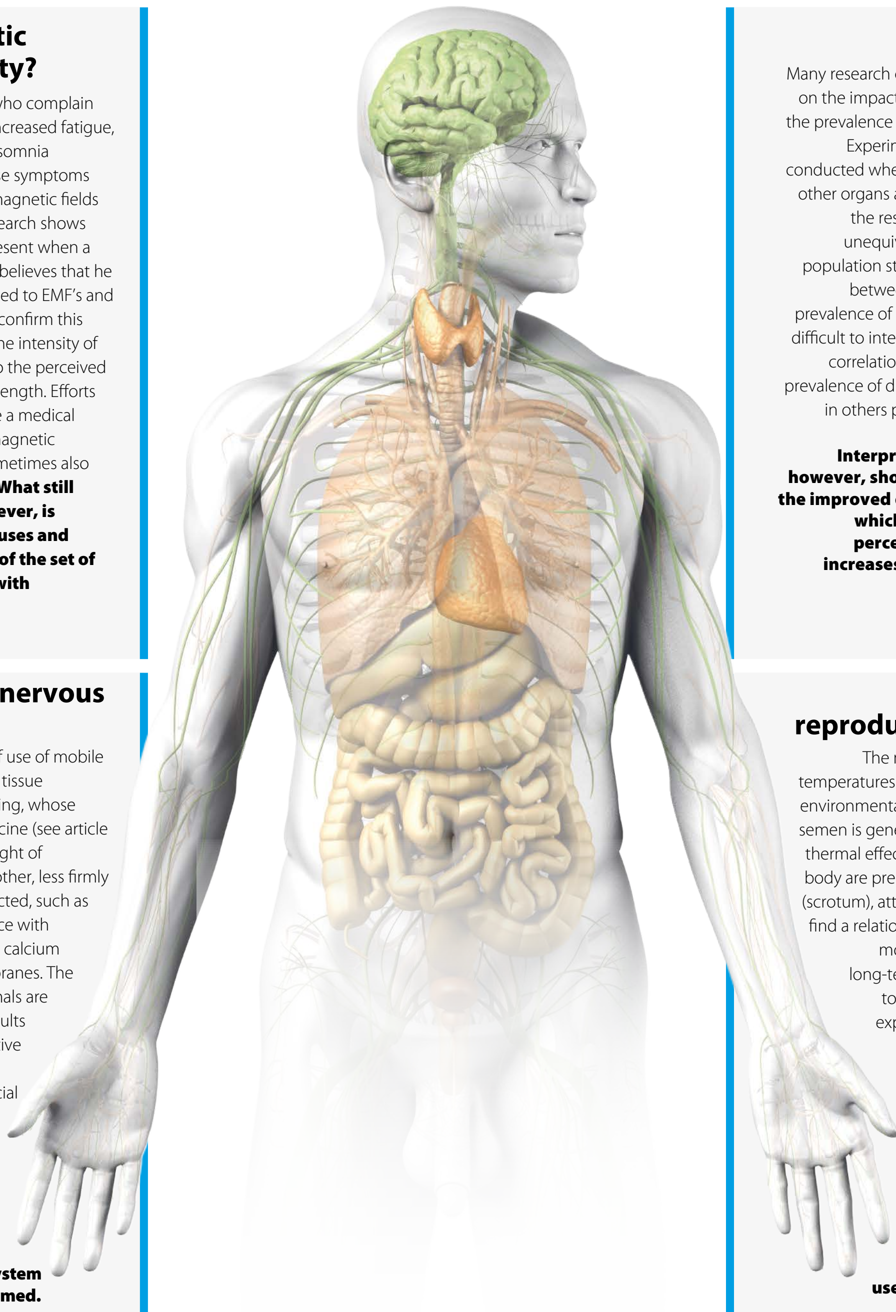
Electromagnetic radiation interacts with the human body in various ways, depending on the radiation wavelength. In the case or radio waves and microwaves, the effects are mostly thermal or, in simpler terms, an increase in the temperature at the surface of the body. There are discussions about other forms of interaction but science has not found any convincing evidence of their presence.

Electromagnetic hypersensitivity?

A few percent of people who complain about such problems as increased fatigue, headache, tinnitus, and insomnia associate presence of those symptoms with the effect of electromagnetic fields (EMF) on their bodies. Research shows that the symptoms are present when a given person subjectively believes that he or she is particularly exposed to EMF's and not when measurements confirm this exposure: consequently, the intensity of the symptoms is related to the perceived and not the actual field strength. Efforts have been made to define a medical condition called "electromagnetic hypersensitivity" (EHS), sometimes also called "electrosensitivity." **What still needs to be done, however, is identification of the causes and precise determination of the set of symptoms associated with electrosensitivity.**

Impact on the nervous system?

The most obvious effect of use of mobile phones is local increase of tissue temperature. Besides heating, whose effects are known to medicine (see article II.2 and the blocks to the right of infographic), presence of other, less firmly confirmed effects is suspected, such as oxidative stress, interference with functioning of synapses or calcium channels in neuron membranes. The results of research on animals are unclear: some research results confirm presence of negative effects while others demonstrate quite beneficial effects of fields in some neurodegenerative diseases.
Based on available research results, the effect of electromagnetic fields on the nervous system cannot be clearly confirmed.



Cancer?

Many research centers conduct research on the impact of mobile phone use on the prevalence of head and neck cancer. Experiments on animals are also conducted where the effects of EMFs on other organs are studied. The results of the research on animals are not unequivocal. On the other hand, population studies on the relationship between exposure to EMFs and prevalence of cancer in people are very difficult to interpret: in some studies, no correlation between exposure and prevalence of diseases is observed, while in others prevalence increases with exposure.
Interpretation of the results, however, should take into account the improved diagnostics of cancer, which does not change the percentage of patients but increases the detection rate of diseases.

Impact on the reproductive system?

The negative impact of higher temperatures of the testicles and many environmental factors on the quality of semen is generally known. Because the thermal effects of EMFs on the human body are present mostly at the surface (scrotum), attempts are being made to find a relationship between disturbed morphology of sperms with long-term exposure of the body to EMFs. The results of both experiments on animals and tests of human semen are not unambiguous.
We cannot definitively state that decreased motility and vitality of sperm are due to sedentary lifestyle, wearing tight clothes, frequent hot baths, use of sauna, or exposure to EMF.

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III. *Standards and measurements*

Introduction

- Safety standards protect the health of citizens and reduce the natural fears associated with unknown technologies.
- The first regulations concerning the limitation of exposure to electromagnetic fields were adopted during the Cold War. The Eastern Bloc countries had stricter rules than the West.
- The regulations in force in Poland hinder the performance of projects consisting in the construction of base stations and their operation.

    - Every device powered by electricity generates an electromagnetic field, whether it is a desired effect (like in the case of e.g. a mobile phone) or completely a side effect (like in the case of e.g. a vacuum cleaner). The development of devices that generate an artificial electromagnetic field is accompanied by the development of laws aimed to protect people and the environment against this field.
    - The recommended exposure limit values for electromagnetic fields were adopted based on scientific research and contain a very wide safety margin.
    - The relevant Polish laws are more restrictive than laws of other EU countries.

- The applicable laws precisely regulate the type, the locations, and the methods of measurement of the level of electromagnetic field in the environment.
- In Poland, measurements of electromagnetic field levels are performed by accredited laboratories.
- Alternative measurement methods, including simulated field distribution analyses, may be of auxiliary nature.

    - General public exposure to the electromagnetic field in Poland is kept on a low level.
    - Measurement results are collected and made available in various locations, forms, and modes.
    - The SI2PEM system, which is being prepared, will enable collection, processing, and making available relevant data on electromagnetic field levels nationwide.

III.1 Standards and safety

Grzegorz Czwordon

A standard – in the context of technical regulations, which is important in this case – is a document that describes the verified state of technical and scientific knowledge, is intended for use on a voluntary basis, and serves to facilitate and simplify the flow of goods and services between markets. It may also form the basis for an agreement between the economy, the governmental, and the public as to meeting of certain safety and quality conditions for products and services. Standards are the quintessence of knowledge of the members of standardization committees who are experts in their respective fields. On the national level, the term **standard** has two different meanings. It can mean either a certain quality level or a normative document.

Standards are a part of everyday life in today's society, but many people are not even aware of their existence. The houses that we live in, the cars that we drive, and the devices that we use are built according to specific standards, so that they work correctly and are safe to use.

A good example of products made according to a certain standard are electrical appliances. We buy a new device and we simply expect it to work properly once we plug in into the power socket. Similarly, in the case of mobile phones or wireless networks, we expect that the phone will work wherever we are and we do not think about how it works.

In terms of safety, standards in most situations function "quietly," as if in the background, but are based on many years of research and development. Safety and security are relative and depend on changing circumstances – like the whole world around us. This concept applies to many spheres of public life. These include security of the state, national security, external security, internal security, public security, universal safety and security, safety of people, security of property, security of public order, and also security associated with civil defense, extraordinary threats to the environment, fire protection, and working environment, as well as crises and crisis management[1].

Wireless technology is no exception in this regard – for many decades, research conducted worldwide has contributed to the development of standards that guarantee the required, ever-increasing level of safety for users. Freedom from threats, defined as a state of functioning of humans in the world around them, does not actually mean their complete absence, but rather their acceptable level. This also applies to the interaction of the electromagnetic field and its fixed general public limits. Therefore, in order to understand the next chapters of this block, it turns out to be important to first explain what safety actually is.

It should be noted that all people want to feel safe. As indicated, e.g. by Abraham Maslow, the need for safety is one of the most fundamental needs of every human being[2]. Generally, it should

1 P. Tyrała. "Zarządzanie kryzysowe" [Crisis management]. Wydawnictwo Adam Marszałek, Toruń 2006.

2 A. Wadeley, A. Brich, T. Malim. "Wprowadzenie do psychologii" [Introduction to psychology]. PWN, Warsaw 2000.

be understood as a condition that ensures protection of life, health, property, and other values against unlawful activities and protection of the principles of social coexistence and relationships governed by legal norms[3]. On the other hand, pragmatically, the state of safety is defined by established safety standards adopted by the society that are adequate given the level of technological and cultural development and the objective constraints of the environment[4].

Two worlds: ensuring safety with regard to radio-frequency electromagnetic fields – historical background

The development of radio technology is very much connected to World War II and the widespread use of radar technology by the military. Consequently, as late as in the 1950's and the 1960's, the first research in bioelectromagnetics was conducted by both the American military and Soviet scientists. In the 1950s, restrictions were first recommended and applied to the exposure of people, mainly in workplaces, to electromagnetic fields. For example, in the United States, many organizations have recommended and adopted limits on the power density in the range of 1 to 1,000 W/m^2. The first value was assumed to be safe in all conditions, while exposure to radiation above the latter value was assumed to be dangerous. When the results of new research appeared, the widely differing limit values began to be reduced to a single value of 100 W/m^2 for continuous exposure of the entire body. For the first time these values were recommended by the U.S. Department of the Navy in 1953 and were based on a simple thermal model that referred to the phenomenon of clouding of the eye's lens as a result of an increase in body temperature, but supported by experimental data. This data indicated that the threshold for lens clouding was higher than 1,000 W/m^2.[5]

The first draft of formal standards was initiated in 1960, when the American Standards Association (currently American National Standards Institute – ANSI) approved the draft safety standards for radio-frequency electromagnetic fields. This project involved the creation of the C95 Committee, whose task was to develop these standards by reaching an open consensus. The Committee published the first standard in 1966[6], followed by revisions in 1974[7] and 1982.[8] The most recent revision of the standard concerned a single-level reduction in exposure for the general public and employees. In 1988, the C95 Committee continued its work as the Standards Coordinating Committee 28 (SCC28) under the auspices of the Standards Council of the Institute of Electrical and Electronics Engineers (IEEE). The IEEE C95.1-1991 standard issued in 1999[9] contained more realistic averaging of time at millimeter wave frequencies and limits on induced current to exclude the possibility of skin burns at short exposures and the occurrence of induced contact. Unlike many contemporary standards and guidelines, this standard contains specific principles of implementation and formal procedures of response to requests for intervention.

3 R. Jakubczak (ed.). "Ochrona narodowa w tworzeniu bezpieczeństwa III RP" [National protection in the formation of the security of the 3rd Polish Republic]. Bellona, Warsaw 2003.

4 A. Czupryński, B. Wiśniewski, J. Zboina (ed.). "Bezpieczeństwo. Teoria – Badania – Praktyka" [Security. Theory – Research – Practice]. Wydawnictwo Centrum Naukowo-Badawczego Ochrony Przeciwpożarowej im. Józefa Tuliszkowskiego Państwowego Instytutu Badawczego, 2015.

5 W.W. Mumford. "Some technical aspects of microwave radiation hazards." *Proceedings of the IRE.* 1961; 49(2): 427-447.

6 American Standards Association. "Safety levels of electromagnetic radiation with respect to personnel. USASI standard C95.1-1966." 1966.

7 American National Standards Institute. "Safety levels of electromagnetic radiation with respect to personnel. ANSI standard C95.1-1974." 1974.

8 American National Standards Institute. "Safety levels of electromagnetic radiation with respect to human exposure to radio frequency electromagnetic fields, 300 kHz to 300 GHz. ANSI standard C95.1-1982." 1982.

9 Institute of Electronics and Electrical Engineers. "IEEE Standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz. IEEE Std. C95.1-1991" (1999 Edition). 1999.

During the Cold War, Russians and other countries of the Eastern Block introduced strict safety standards, which they considered at that time to be justified from the geopolitical standpoint. The first standards concerned workers' exposure to radio-frequency electromagnetic fields and were introduced in the Soviet Union in 1958. Western scientists strongly criticized the first Soviet research both for philosophical reasons and for strictly factual reasons, such as the lack of proper reporting of measurement methodologies and access to data, defective statistical analysis, inadequate control (supervision of the research), and largely subjective interpretation of the results obtained. The Soviet standard was also a constant source of controversy and even became the subject of discussion in the US Congress when the first legislation on potential hazards associated with radio-frequency electromagnetic fields was drafted[10].

Standards for exposure of the general public were adopted much later. Since the 1950s, such institutions as the Ministry of Health, the Military Medical Academy, and the Institute of Aviation and Space in Moscow financed research on the impact of the electromagnetic field on human health. It was the results of this research that formed the scientific basis for the development of the first universal safety standard published in 1978.[11] Unfortunately, for geopolitical reasons, only few studies that formed the basis of the Soviet and Russian standards were published outside of the USSR.

The general approach to protection of the public against the negative effects of electromagnetic fields in the countries of the Soviet bloc assumed that citizens should not be exposed to any physiological changes (thermal or non-thermal) induced by exposure to this field, even if it is not scientifically demonstrated that it is harmful to health. Consequently, the final electromagnetic field limits were set as a certain fraction of the minimum exposure to a radio-frequency electromagnetic field that can cause physiological (adaptive-compensatory) reactions in humans[12].

The authorities of most countries want to know what health effects they protecting their citizens against and do not make *ad hoc* assumptions about the effects. This is also the philosophy of the International Commission for Non-Ionizing Radiation Protection (ICNIRP) and the IEEE Committees. On the other hand, in various agencies of the former USSR, special internal studies were conducted for many years based on the methodological recommendations adopted in 1981 by the Ministry of Health of the Ukrainian SSR[13] for assessment of the biological effects of low-intensity microwave radiation for standards in the environment. They become the basis for developing standards. When evaluating these studies, however, one should keep in mind that they were carried out about 30-50 years ago (at the present rate of scientific progress, this is a very long time), when many issues concerning e.g. the human immune system were not yet known, and modern laboratory techniques and standards of high quality research were not available. What was also problematic was that each study conducted on animals involved a small population of specimens who differed in terms of various physical characteristics and living conditions.

Furthermore, the lack of raw data prevented an objective evaluation of the results and correct elaboration of the findings. In the period when the research was carried out, i.e. during the Cold War, the exchange of scientific information between the Soviet Union and countries of the West practically did not exist. The research conducted in the West was subject to reviews and changes, which cannot be said about the research conducted in

10 S.P.A. Bren, "Historical Introduction to EMF Health Effects." *IEEE Engineering in Medicine and Biology Magazine.* 1996; 15(4): 24-30.

11 USSR Standard, "Standard for Public Exposure, SN-1823--78/1978." Moscow 1978 [after:] WHO, "Radiofrequency and microwaves. Environmental Health Criteria No. 16." Geneva, 1981.

12 M. Repacholi, Y. Grigoriev, J. Buschmann, C. Pioli. "Review: Scientific Basis for the Soviet and Russian Radiofrequency Standards for the General Public." *Bioelectromagnetics*. 2012; 33: 623-633.

13 Ministry of Health of the Ukrainian Soviet Socialist Republic. "Methodological recommendations for the assessment of biological effects of low intensity microwave radiation for hygienic regulation in the environment." 1981.

the USSR or countries of the Eastern Block. The results of the Soviet research should be interpreted in this context. After the break-up of the Soviet Union, the development of Russian standards continued to be based on a similar methodology and an approach aimed at protecting the public from exposure to radio-frequency electromagnetic fields. The Soviet philosophy for the protection of the public, which assumed that the exposure of people to radio-frequency electromagnetic fields should not trigger any compensatory reaction, is no longer applied except for Russia, Poland, and Bulgaria[14].

Why we are afraid of the electromagnetic field

Lack of knowledge and misunderstanding of physical phenomena lead to fear of their widespread use. Simply put, people are usually afraid of what they do not understand and do not know. This used to be the case with electricity – when electric lamps first appeared, people were forbidden to approach them and they were turned on and off only by domestic servants. Even greater concern was raised at the beginning of the 20th century by the construction of sanitary sewage systems in cities, which was expressed in the brochure published in 1900 in Cracow, titled "Sewer system of the City of Warsaw as a tool of Judaism and chicanery to destroy Poland's agriculture and to exterminate Slavic population on the banks of the Vistula"[15] by anonymous author (signed as F. R. farmer on the Vistula). This text provides a good illustration of the operation of all kinds of conspiracy theories.

Nowadays, the situation is similar with regard to the electromagnetic field and new technologies. Over the years, fears of direct and then long-term impact of the electromagnetic field on human health have developed. At the end of the 1970s, it was demonstrated that these fears are largely

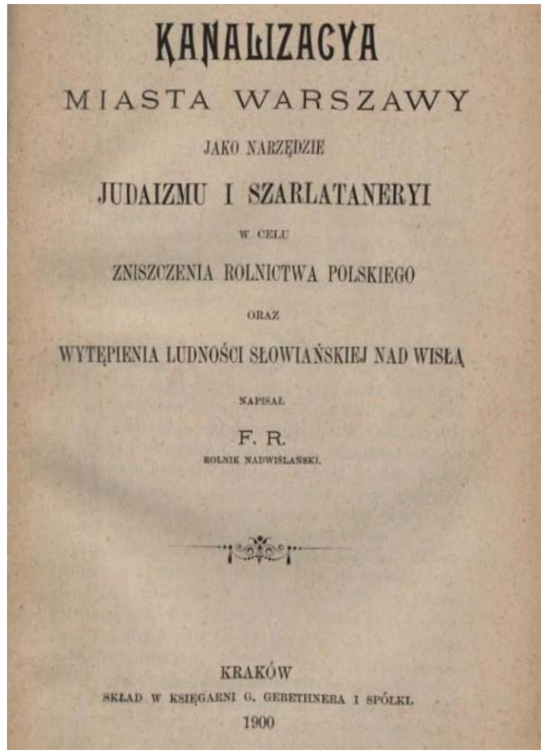
KANALIZACYA
MIASTA WARSZAWY
JAKO NARZĘDZIE
JUDAIZMU I SZARLATANERYI
W CELU
ZNISZCZENIA ROLNICTWA POLSKIEGO
ORAZ
WYTĘPIENIA LUDNOŚCI SŁOWIAŃSKIEJ NAD WISŁĄ
NAPISAŁ
F. R.
ROLNIK NADWIŚLAŃSKI.
KRAKÓW
SKŁAD W KSIĘGARNI G. GEBETHNERA I SPÓŁKI.
1900

Fig. 1. The cover of the booklet published in 1900 titled "Sewer system of the City of Warsaw as a tool of Judaism and chicanery to destroy Poland's agriculture and to exterminate Slavic population on the banks of the Vistula." Source: Wikimedia Commons

based on disinformation[16], which was present in the writings of some skeptics and opponents of the microwave technology[17]. With time, they increased and partly transformed into a generalized electrophobia[18]. In the early 1990s, this situation intensified because of the fear of the electromagnetic field produced by power lines[19] and resulting from continuation of research on the long-term chronic effects of radio waves. Contrary to scientific reports, in the eyes of the public, these phenomena were dangerous. Fear of the field with

14 Ibid.

15 See: https://polona.pl/item/kanalizacya-miasta-warszawy-jako-narzedzie-judaizmu-i-szarlataneryi-w-celu-zniszczenia,MzAwMzUyMA/2/#info:metadata.

16 J.M. Osepchuk, "Microwaves in the media: truth or consequences." *1979 IEEE MTT-S International Microwave Symposium Digest*. 1979; 11-14.

17 E.g. P. Brodeur. "The Zapping of America." William Morrow, New York, 1978.

18 E.R. Adiar, "Nurturing electrophobia." *IEEE Spectrum*. 1990; 27: 11-14.

19 I. Nair, M.G. Morgan, K.F. Floring. "Biological effects of power-frequency electric and magnetic fields. Report OTA-BP-E-53." U.S. Govt. Printing Office, Washington D.C., 1989.

the frequency of 60 Hz, which supposedly causes cancer, was limited in popular literature to the field produced by power lines, and not by devices and other common sources of exposure, which is explained by the constant exposure associated with the operation of the former (and transitional exposure in the case of the latter)[20]. Additionally, such media as "Microwave News" [21] intensified the fear of long-term impact without any relation to the strength of the electromagnetic field and departed from scientifically supported considerations about the effects of energy absorption by the human body.

Opposition to the impact of artificial electromagnetic fields was well publicized in American media and referred to the following sources of electromagnetic field (in chronological order): radars, microwave ovens, high-voltage power lines, relay towers, video terminals, transmission towers, power lines (medium- and low-voltage), electric blankets, police radars, mobile phones and base stations, and currently 5G networks. These media attacks, however, omitted such devices as baby monitors, which emit a stronger electromagnetic field than most police radars. Many other household appliances, electric trains, medical procedures, as well as sources of infrared and optical radiation, such as lasers, halogen lamps, and now also LED lamps have been indicated. Therefore, for almost 30 years, as a result of appearance of occasional research showing negative impact of the electromagnetic field, based on weak and incoherent evidence, many groups have more and more clearly called for abolition of standards based on reference levels (maximum permitted levels).

Instead, they suggest a precautionary policy[22] or communication of risks[23], in which no established limit value related to exposure to an electromagnetic field is considered safe contrary to scientific evidence[24]. these are clearly non-scientific concepts that support hypersensitivity and application of the precautionary principle. This is related, like the ALARA principle, to the hazards caused by chemical agents and to the ionizing radiation, but without any scientific basis in this regard.

Due to the difficulties associated with repetition of researched that demonstrated negative biological effects of the impact of the electromagnetic field and to the numerous ambiguities and inconsistencies appearing in those studies, as early as in 1987, the term "Cheshire cat" was adopted to describe such tests to emphasize their elusive nature[25]. Unfortunately, people are afraid of what they cannot see and, at the same time they accept the noticeable sources. This is the case with radio-frequency electromagnetic fields, which undoubtedly deserve more rational acceptance than infrared radiation or the energy of visible light, especially since the latter constitutes a much greater threat than infrared radiation and microwave or radio waves, which are invisible. It is essential that safety standards related to the electromagnetic field be reasonable, and excessive safety margins which could compromise the effectiveness of technological solutions for the benefit of mankind should be avoided. Situations must be avoided where systems that prevent the lethal effects of hazards such as electric shock cannot function due to toughening of electromagnetic field limits. It is also important that safety margins are reasonably and evenly distributed over the entire radio spectrum and standardized worldwide so as not to give an unfair advantage to certain manufacturers of competing products or systems who use different spectrum ranges. Similarly, the existence of different standards around the world hinders free trade, movement of goods, and use of services.

20 P. Brodeur. "Currents of Death." Simon & Schuster, New York, 1989.

21 *Microwave News*, Vol. 2, New York, 1990.

22 M.G. Morgan. "Prudent avoidance." *Public Utilities Fortnightly*. 1992; 26-29.

23 H.K. Florig. "Containing the costs of the EMF problem." *Science*. 1992; 257: 468-469.

24 J.M. Osepchuk, R.C. Petersen. "Historical Review of RF Exposure Standards and the International Committee on Electromagnetic Safety (ICES)." *Bioelectromagnetics Supplement*. 2003; 6: S7-S16.

25 E.L. Cartensen. "Biological Effects of Transmission-Line Fields." Elsevier, New York, 1987.

In recent years, universal access to the Internet has resulted in the problem of fake news. Hundreds of alarming materials have been published concerning negative effects of electromagnetic fields and mobile technologies (in particular 5G networks). These materials, however, are not based on facts. They are distributed mainly due to the desire to attract readers, which translates into improved viewing statistics for the website, generating revenue from advertisements, or achieving other goals that are important to the authors of the materials. Therefore education of the society on such important issues is crucial.

Precautionary principle – what is it?

Poland, along with Russia and China, has the strictest protection policy, especially for children, against possible negative effects of radio-frequency electromagnetic fields[26]. This applies not only to established maximum permitted levels of electromagnetic fields in the environment, but also to measurement methodologies, control, regulations concerning the investment process, environmental regulations, and determination of locations accessible to the public. Opponents of new technologies (including 5G networks) very often make references to the lists published by the BioInitiative Working Group, which, in addition to proving the harmfulness of electromagnetic fields, are intended to discredit such international entities as the World Health Organisation (WHO) and the ICNIRP. Opponents of new technologies also call for inclusion in those organizations of under-represented countries, such as Russia, China, Turkey, and Iran, whose research communities have supposedly carried out the majority of the research on non-thermal effects of the impact of radio-frequency electromagnetic fields in recent years[27]. From the political standpoint, one can seriously doubt that these countries care about safety and freedom of their citizens and suspect that this is rather an attempt to delay Western countries in the technology race, which could be considered a manifestation of a new Cold War. This is a very valid statement, given that Russia recommends that people under 18 should not be allowed to use mobile phones at all and Turkey is working on legislation prohibiting the use mobile phones by children under 14[28].

Few risk management policies have caused as much controversy in the world as the precautionary principle. On general, it conforms to the earlier precautionary approach, with the difference is that it was referred to in numerous international treaties and declarations. Under the Treaty on European Union of 7 February 1992, it is the basis for the European environmental law and plays an increasingly important role in development of environmental health policies. The biggest problem related to the precautionary principle is the unfortunate lack of its definition. This results in freedom of interpretation, the strongest expression of which is the formulation of the requirement, specifically in accordance with the precautionary principle, that safety must absolutely be confirmed before new technologies can be implemented. Looking further, the 1982 World Charter of Nature states that where potentially adverse effects are not fully understood, activities should not be continued. If this position is interpreted literally, it is easy to come to the simple conclusion that no new technology is capable of meeting this requirement.

Actions of individual countries show different precautionary approaches also in relation to the electromagnetic field. On the one hand, there is Italy, which in 1998 introduced the so-called "warning limits," and Switzerland, which in 1999 established just as low so-called "precautionary limits" for particularly sensitive areas (e.g. places of residence, schools, and hospitals) and prohibited the construction of new facilities in areas where these "precautionary limits" have been exceeded[29]. On

26 M. Redmayne. "International policy and advisory response regarding children's exposure to radio frequency electromagnetic fields (RF-EMF)." *Electromagnetic Biology and Medicine*. 2016; 35(2): 176-185.

27 L. Hardell. "World Health Organization, radiofrequency radiation and health – a hard nut to crack (Review)." *Int J Oncol*. 2017; 51(2): 405-413.

28 M. Redmayne. "International policy...," op. cit.

29 K.R. Foster, P. Vecchia, M.H. Repacholi. "Science and the Precautionary Principle." *Science*. 2000; 288: 979-981.

the other hand, there are such countries as New Zealand, which at the same time (in 1999) established limit values that comply with international guidelines, while further recommending that exposure to radio-frequency electromagnetic fields be reduced to a minimum and obliging the industry to carry out activities to address public concerns[30]. Polish regulations already take into account at many levels the precautionary principle in relation to telecommunication systems that are the source of electromagnetic fields. On the one hand, this concerns the required permits associated with the location and operation of telecommunication equipment, environmental issues, and determination of places accessible to the public: on the other hand this concerns a very strict methodology for measuring field values, systematic monitoring by environmental-protection agencies, and educational activities. A change of one of these elements (e.g., an electromagnetic field strength limit value) does not mean that the precautionary principle is waived. It will continue to keep the impact of the field on people as low as reasonably possible. Interestingly, Polish legislation treats mobile phones (which are also a source of the electromagnetic field, like any other electrical devices) in the same way as recommended by the Council of the European Union in Recommendation no. 1999/519/EC. In the case of high-voltage power systems – it is twice as liberal. Only in the case of radio telecommunication systems they are a hundred times more stringent.

In 2000, the European Commission emphasized in its communication[31] that the precautionary principle can only be invoked in the event of a possible threat and under no circumstances can it justify an arbitrary decision. The invocation of the precautionary principle is therefore justified if three prerequisites are met:

- potentially negative effects have been identified;
- evaluation of the available scientific data has been carried out; and
- there is no scientific certainty.

Three specific principles form the basis for invoking the precautionary principle:

- its implementation should be based on the fullest possible scientific assessment, which should best determine the degree of scientific uncertainty;
- any possible action should be accompanied by an assessment of the risk and the possible effects if any action is not taken;
- as the results of the scientific or hazard assessment become available, all interested parties should have the opportunity to examine different precautionary measures.

When the precautionary principle is invoked, in addition to the specific principles, five general principles are applied, which serve as the guidelines for its application:

- the measures taken must be proportionate to the target safety level and must not aim at a zero risk;
- the measures must not be used in a discriminatory manner;
- the measures must be consistent with those adopted in situations similar to or based on a similar approach;
- the potential benefits and costs of a given action or lack of action must be subject to economic analysis;
- in the light of scientific progress, the measures must be re-examined, i.e. they must be temporary pending the availability of more reliable scientific data.

In most cases, consumers and associations that represent them must prove the existence of a hazard associated with the procedure or product placed on the market: however, this obligation

30 New Zealand Ministry for the Environment and Ministry of Health. "Towards national guidelines for managing the effects of radiofrequency transmitters: A discussion document." 1999.

31 The communication is available at: http://europa.eu/rapid/press-release_IP-00-96_en.htm.

does not include medicines, pesticides, and food additives.

Despite the adoption by the Commission of the communication on the precautionary principle, there is still no clear guidance on the weight of the evidence for application of this principle. The rationale for using it to reduce public exposure to radio-frequency electromagnetic fields well below the thresholds set by the international committees also remains a matter for debate. And vice versa: how much proof of safety must be provided to opponents of new technologies for them to be approved[32]? It is clear, however, that these issues will continue to arouse much controversy and will be the subject of many disputes, not only in Poland. It should be emphasized that introduction, under public pressure, of additional restrictions to the existing regulations, established on the basis of research results, undermines the credibility of science and of the existing regulations.

Regulation or overregulation of wireless telecommunication infrastructure?

Investment projects in mobile networks are particularly difficult in Poland. Installations that emit electromagnetic fields have been identified, in the light of national legislation[33], as having significant environmental impacts, although this does not result from EU regulations (such installations are not included in Annexes I and II of Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment, i.e. in the group of projects that should be assessed from the point of view of their effects in the environment).[34]

The introduction of an obligation to carry out an environmental impact assessment for these installations has resulted in discrepancies in interpretation and application of the provisions of the construction law[35]. The procedure related to an environmental impact assessment for a planned project is generally carried out at the stage of issue of the environmental constraints decision for the project. As a part of the environmental impact assessment for a project, the risk of serious accidents and natural and construction disasters, the required scope of monitoring, the natural compensation, and the possibilities and methods of prevention and reduction of the negative impact of the project are determined, analyzed, and assessed. The indirect impact of the project on the environment, the population, the health and living conditions of people, monuments, material assets, and landscape are also analyzed and assessed. On the other hand, in the case of radio-frequency electromagnetic fields, as shown in article II.2. on page 58, which focuses on biomedical issues, the scientific uncertainty about their harmfulness is too high.

In practice, this means that, at the stage of the environmental constraints procedure, the owner bases its documentation on research showing no negative impact on the environment and people, while other parties to the proceedings (even later, at the administrative stage) or the opponents of the technology use research showing harmfulness of either electromagnetic fields or the technology itself. Thus, we are going back to the issue of zero safety and the lack of consensus concerning the legislation applicable to the electromagnetic field. Direct and indirect impact should be based on actual damage, i.e. the emission of pollutants (keep in mind that emission of electromagnetic fields is

32 K.R. Foster et al., op. cit.

33 The Act of 3 October 2008 on providing access to information on the environment and its protection, participation of the public in the environmental protection, and environmental impact assessments (Journal of Laws of 2017, item 1405) and the Regulation of the Council of Ministers of 9 November 2010 on projects that may have a significant impact on the environment (Journal of Laws of 2016, item 71).

34 See: http://eur-lex.europa.eu/legal-content/PL/TXT/PDF/?uri=CELEX:32011L0092&from=PL.

35 Act of 7 July 1994 – Construction law (Journal of Laws of 2018, item 1202, 1276, 1496, 1669, 2245; Journal of Laws of 2019, item 51).

not pollution), as well as on actions consisting in removal of existing trees and shrubs, interference in natural habitats of protected animals, etc. This is necessary in order to properly determine the methods of prevention and reduction of negative impacts or the need for environmental compensation. However, no person in the world is able to determine the measurable negative effects of the impact of radio-frequency electromagnetic fields and to identify specific measures to prevent and minimize this impact, not to mention environmental compensation. This brings us back to the past and to the Soviet philosophy related to determination of the levels of permissible electromagnetic fields. Moreover, as already indicated, in the light of Polish law, in particular environmental protection law[36], emission of the electromagnetic field is not considered as pollution, and yet is subject to specific inspection and monitoring[37], and a procedure of notification to environmental-protection authorities. At the same time, the permissible levels of general public exposure to the electromagnetic field should not be exceeded: otherwise, the Chief Inspector of Environmental Protection is required to keep a register of places where exceeded levels have been identified. Less strict regulations apply in Poland for example to smog levels – a widespread problem in our country – which have a documented serious impact on human health.

As a result of such perception of the issues related to radio-frequency electromagnetic fields, even those devices (e.g. antennas) that should not be subject to the construction law (because they are not construction equipment), must undergo the procedure of notification of their installation as construction work (except for those installed in Natura 2000 areas and on monuments which require a building permit); in addition, such projects are put in question by opponents of new technologies and people who are concerned about their health or loss of value of their property. Due to public pressure, issues that legally are subject to the environmental protection law are subject to the construction law. In particular, this applies to modification of the settings of technical equipment (antennas) that affect e.g. exposure in places accessible to the public or to replacement of devices with new ones in the event of their wear or failure. Common-sense would make it impossible to consider such activities as construction work; however, there are many cases brought before administrative courts, which often agree with the position of the applicants. For all of these reasons, it can be concluded that not only the investment project process for mobile telephony base stations but also the later stage of their operation are subject to excessive, unreasonable legislation.

Participation of the public in the investment process

The existing legislation guarantees effective participation of citizens, as parties to administrative proceedings, in the investment project process, including projects of construction of freestanding telecommunication masts. This takes place at the following stages of projects:

- obtaining a decision for projects that can always have a significant environmental impact;
- obtaining a decision for projects that can potentially have an environmental impact;
- assessment of the impact of the planned project on a Natura 2000 area (if an environmental impact report is prepared);
- determination of the location of the project (based on the zoning plan or on the decision on determination of the location of a public-purpose project);
- obtaining a building permit decision.

Every citizen has the right to approach the relevant building supervision inspector with a request to carry out an inspection to verify whether the construction or completion of an installation complies with applicable law. If any irregularities are found,

36 Act of 27 April 2001 – Environmental protection law (Journal of Laws of 2017, item 519).

37 Act of 20 July 1991 on the Inspection for Environmental Protection (Journal of Laws of 2016, item 1688).

the findings from the inspection may give rise to further proceedings to ensure compliance of the project with the law.

Citizens can also confirm compliance with environmental standards (electromagnetic field limits). For this purpose, a local government unit should be requested, pursuant to Article 17(3a) of the Act on Environmental Protection, to check the levels of the electromagnetic field emitted by the radio telecommunication installation.

III.2
Standards applicable to the electromagnetic field

Rafał Pawlak, Barbara Regulska

Protection of people and the environment against the electromagnetic field

Due to the dynamic development of mobile telephony, in the early 1990s, the World Health Organization, acting within the framework of the United Nations, has undertaken research on the biological effects of radio-frequency electromagnetic waves. As a result of this work, precise guidelines for limitation of exposure to electromagnetic fields with frequencies up to 300 GHz were specified in 1998 in order to ensure protection of people and environment against known adverse health effects.[1] These guidelines were prepared in collaboration with the WHO by an organization of independent scientists, operating in the framework of the *International Commission on Non-Ionizing Radiation Protection* (ICNIRP). On this basis, on 12 July 1999, the Council of the European Union[2] adopted a document, usually referred to by its abbreviated name Recommendation 1999/519/EC. It is regarded as the basic act of the European Union related to the protection of the public against electromagnetic fields.

1 ICNIRP, "Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)," *Health Physics*. 1998; 74: 494-522.

2 Official Journal of the European Communities, "Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)," July 1999.

Recommendation 1999/519/EC defines two quantities:

- **basic restrictions** related to directly occurring phenomena in human bodies – especially the thermal effect (see article II.1. on page 50);
- **reference levels** – limit values that are considered safe, serving the purpose of practical verification (by measurement) that exposure to electromagnetic fields does not exceed the limit values.

General public exposure – basic restrictions

Basic restrictions in the 10 MHz to 10 GHz radio frequency range are defined in the Recommendation 1999/519/EC by means of the SAR rate (*Specific Absorption Rate*) expressed in [W/kg]. The SAR is a measure of the rate of absorption of electromagnetic energy converted in the tissues of a human body into heat and, in practice, means the power absorbed by a unit of body weight. As a result of penetration of the electromagnetic field into the human body, a part of that field is absorbed and converted into heat in the tissues. The increase in the temperature of the human body by one degree Celsius has been determined to occur when the body absorbs 1 W/kg for one hour or the equivalent of 4 W/kg for 6 minutes. Consequently, the SAR limit values were set as averaged in 6 minutes:

The limit value indicated in Recommendation 1999/519/EC, SAR = 0,08 W/kg, averaged for the entire human body, has been determined taking into account a safety factor of 50, which is a high value.

- for the entire human body, averaged value: 0.08 W/kg;
- for local exposure – the head and the trunk: 2 W/kg;
- for local exposure – limbs: 4 W/kg.

The limit value indicated in Recommendation 1999/519/EC, SAR = 0,08 W/kg, averaged for the entire human body, has been determined taking into account a safety factor of 50, which is a high value. What is the reason for this value?

The value of SAR = 4 W/kg, indicated in the ICNIRP Recommendation, averaged over a period of 6 minutes, was taken as a reference (electromagnetic energy absorption at such a rate can lead to a thermal effect, consisting of an increase in body temperature by not more than 1°C). A 10-fold safety factor was then adopted, resulting in the value of the SAR acceptable for occupational exposure (in the occupational health and safety sense) and providing a sufficient safety margin:

$$SAR = 4 / 10 \text{ W/kg} = 0.4 \text{ W/kg}$$

Next, a 5-fold safety factor was adopted, resulting in the value of the SAR acceptable for continuous general public exposure:

$$SAR = 0.4 / 5 \text{ W/kg} = 0.08 \text{ W/kg}$$

In short, for general public exposure, Recommendation 1999/519/EC allows a SAR value that is 50 times lower than a value that would increase the temperature of a human body by 1 degree Celsius: for occupational exposure, the SAR value can be 10 times lower. A comparison of the two permissible values of the SAR and the adopted "safety margin" are shown in Fig. 1.

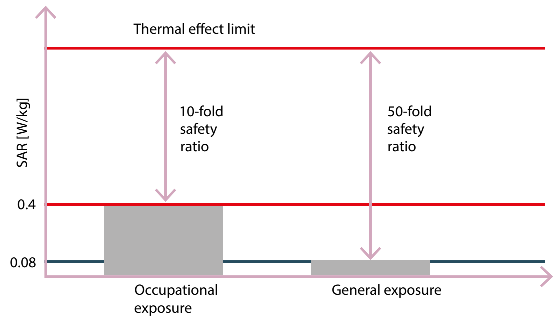

Fig. 1. Comparison of the admissible value of the SAR ratio for occupational exposure and general public exposure with the thermal effect limit value effect - safety ratios.
Author: Paweł Woźniak

General public exposure – reference levels

The reference levels defined in Recommendation 1999/519/EC are closely linked to the basic restrictions. They were established in such a way that, irrespective of the time of presence in an area where the requirements laid down for the reference levels are complied with, the effects of exposure to electromagnetic fields do not exceed the basic restrictions. In other words, if the reference level is not exceeded, then the basic restriction will certainly not be exceeded (and, consequently, there will also be no thermal effect). The reference levels for radio frequencies are defined by measurable quantities, including the RMS value of the strength of the electric component of the field E, expressed in [V/m], and the value of the power density S, expressed in [W/m^2].

The following reference levels were established, expressed as limit values for the electric component of the field E and the power density S, depending on the range of the radio frequency:

- for frequencies from 10 MHz to 400 MHz: E = 28 V/m and S = 2 W/m^2;

- for frequencies (f) from 400 MHz to 2,000 MHz: $E = 1.375 \cdot f^{0.5}$ V/m and $S = f/200$ W/m^2 (f in [MHz]);
- for frequencies from 2 GHz to 300 GHz: E = 61 V/m and S = 10 W/m^2.

An electromagnetic field present in the environment, whose value does not exceed the above reference levels, is considered as safe. For the frequencies, at which typical mobile base stations operate, the following reference levels can therefore be defined, as shown in Tab. 1.

Tab. 1. Reference levels: field strength E and power density S for typical frequencies used in mobile telephony networks, as defined by Recommendation 1999/519/EC

Reference level	Frequency [MHz]				
	800	900	1,800	2,100	2600
Field strength E [V/m]	38.9	41.3	58.3	61.0	61.0
Power density S [W/m^2]	4.0	4.5	9.0	10.0	10.0

General public exposure and occupational exposure

The electromagnetic field present in a work environment in the case of occupational exposure (in the occupational health and safety sense) is subject to more lenient regulations than the electromagnetic field present in the environment (affecting the total population). This results from the adopted safety factors, as described earlier in this document.

The minimum requirements related to protection of health and safety and applicable to exposure of workers to risks arising from physical agents (electromagnetic fields) are regulated by Directive 2013/35/EU of 26 June 2013[3]. Pursuant to Annex III, the permissible SAR value averaged in the body, in any period of 6 minutes, must not exceed 0.4 W/kg.

Annex III of Directive 2013/35/EU also sets out the limit values for the electric component of the field E and the power density S depending on the range of the radio frequencies:

- for frequencies from 10 MHz to 400 MHz: E = 61 V/m;
- for frequencies from 400 MHz to 2 GHz: $E = 3 \cdot f^{0.5}$ V/m (f in [MHz]);
- for frequencies from 2 GHz to 6 GHz: E = 140 V/m;
- for frequencies from 6 GHz to 300 GHz: E = 140 V/m and S = 10 W/m^2.

An electromagnetic field present in the working environment, in the case of occupational exposure, whose values do not exceed the above reference levels, is considered as safe.

Fig. 2 shows a comparison of occupational exposure limit values (occupational safety and health) according to Directive 2013/35/EU and general

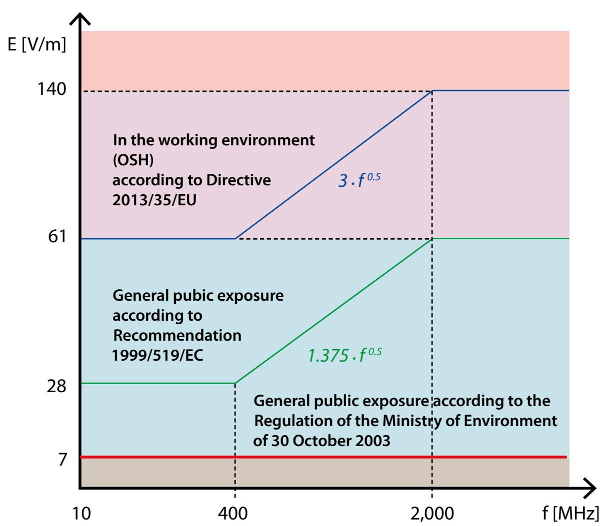

Fig. 2. Comparison of the limit values for occupational exposure in the working environment (OSH) and general public exposure.
Author: Paweł Woźniak

public exposure limit values according to Recommendation 1999/519/EC. For a more complete illustration of the situation, the value of the electromagnetic field allowed in the environment

3 Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields).

applicable in Poland, as specified in the Regulation of the Minister of Environment of 30 October 2003, is also plotted in the graph.[4]

Limit values for electromagnetic fields worldwide

As a set of guidelines, Recommendation 1999/519/EC has become the basis for defining the general public limit values of the electromagnetic field in national legislation of the Member States of the European Union. The member states, responsible for protection of their citizens, may lay down their own restrictions, more stringent[5] than those defined in Recommendation 1999/519/EC. Most member states have established limit values for the electromagnetic field in the environment in accordance with Recommendation 1999/519/EC; however, 9 countries, including Poland, have adopted their own, more stringent regulations governing the protection of the environment against electromagnetic fields[6].

A graphic illustration of the differences in the limit values for the electromagnetic field in the environment adopted by individual EU member states is provided in Fig. 3.

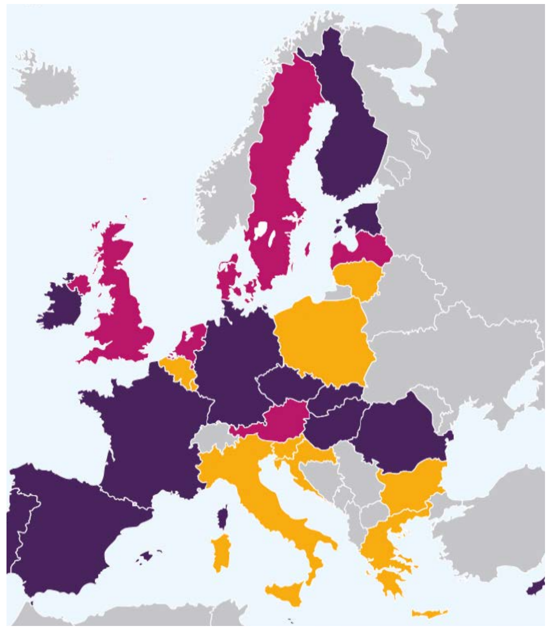

Fig. 3. Illustration of the admissible levels of electromagnetic field in the environment in different European countries (grey: non-EU countries)[5]

Key

- (purple) The applicable limit values of the electromagnetic field in the environment conform to the reference levels indicated in Recommendation 1999/519/EC.
- (magenta) The applicable admissible values of the strength of the electromagnetic field in the environment are less strict than the reference levels indicated in Recommendation 1999/519/EC or there are no regulations at all.
- (yellow) The applicable limit values of the electromagnetic field in the environment are stricter than the reference levels indicated in Recommendation 1999/519/EC.

National regulations on the electromagnetic field in the environment

Poland's first legislation adopted to protect against electromagnetic fields, albeit related solely to occupational exposure and not to the general public, was prepared as early as in the first half of the 1960s[7]. The legislation was the Decree of the Minister of Health Social Security of 20 August 1963 on the health conditions required from workers exposed to microwave electromagnetic fields.

4 Regulation of the Minister of Environment of 30 October 2003 on the admissible levels of electromagnetic fields in the environment and the methods of checking the observance of these levels (Journal of Laws no. 192, item 1883).

5 Based on: "Comparison of international policies on electromagnetic fields (power frequency and radiofrequency fields," 2018).

6 European Commission, "Report on the implementation of the Council Recommendation on the limitation of exposure of the general public to electromagnetic fields (0 Hz – 300 GHz) (1999/519/EC) in the EU Member States", Release 2.1, Brussels, Project Number SI2.489570-SANCO/2OO7/C7/06, 8 May 2008.

7 H. Aniołczyk, "Krajowy system ochrony przed polami elektromagnetycznymi 0 Hz – 300 GHz w świetle aktualnych uwarunkowań prawnych" [National system for protection against 0 Hz – 300 GHz electromagnetic field in the light of the current legal conditions], 2006; 57(2): 151–159; S. Różycki, "Wymagania przepisów dotyczących ochrony człowieka przed polami elektromagnetycznymi występującymi w środowisku" [Requirements set forth in legislation on protection of people against electromagnetic fields in the environment], *Medycyna Pracy*. 2006; 57(2): 193–199.

The first legislation on the protection of people and the environment against this electromagnetic field was the Regulation of the Council of Ministers of 17 November 1980 on detailed rules for protection against non-ionizing electromagnetic radiation that is harmful to humans and the environment.

The acts of law that are currently in force in Poland and that govern the principles of environmental protection (including against the electromagnetic field) are:

- the Environmental Protection Act[8];
- the Act on the Inspection for Environmental Protection[9];
- The Act of 3 October 2008 on provision of information about the environment and its protection, involvement of the public in environmental protection, and environmental impact assessments[10].

Environmental Protection Act

The Environmental Protection Act, which to this day Poland is a set of basic laws regulating the principles of environmental protection against electromagnetic fields, was passed less than two years after the adoption of Recommendation 1999/519/EC.

According to the provisions of Art. 121 of the Environmental Protection Act, compliance with the general public limit values for electromagnetic fields is absolutely mandatory, with the statutory delegation to issue the appropriate im- plementing legislation specifying these values and the means of verification of compliance with them set forth in Art. 122 of the Act.

In addition, according to Art. 122a(1) of the same Act, operators of radiocommunication installations that emit electromagnetic fields are obliged to carry out measurements of the electromagnetic field each time immediately after the commissioning of the installation or the relevant piece of equipment, and each time changes are made to the operating conditions of this installation, if these changes may affect the emissions of the field from this installation.

However, in accordance with Art. 123 of this Act, the provincial environmental protection inspector conducts, within the framework of state environmental monitoring, periodic examinations of electromagnetic field levels in order to assess the levels of electromagnetic field in the environment and to observe its changes.

The implementing legislation to the Environmental Protection Act that regulates the issues related to the obligations of operators of installations that generate electromagnetic field with regard to notification of these installations and performance of electromagnetic field level measurements is:

- Regulation of the Minister of Environment of 30 October 2003 on the admissible levels of electromagnetic fields in the environment and methods of checking the observance of such levels, specifying the admissible levels of the electromagnetic field in the environment for places accessible to the public and the methods of checking their observance;
- Regulation of the Minister of Environment of 2 July 2010 on the types of installations whose operation requires notification, specifying the types of installations whose emissions do not require a permit and whose operation requires notification to the environmental protection authority due to the fact that they generate electromagnetic fields;
- Regulation of the Minister of Environment of 2 July 2010 on the notification of installations that generate electromagnetic fields, specifying the model notification form for installations that generate electromagnetic fields, the operation of which requires notification, and specific requirements for the scope of data contained the notification of such installations.

8 Act of 27 April 2001 – Environmental protection law (Journal of Laws of 2017, item 519).

9 Act of 20 July 1991 on the Inspection for Environmental Protection (Journal of Laws of 2016, item 1688).

10 The Act of 3 October 2008 on provision of information about the environment and its protection, involvement of the public in environmental protection, and environmental impact assessments (Journal of Laws of 2017, item 1405).

The admissible levels of electromagnetic field in the environment in places accessible to the public are specified in Annex 1, Table 2, of the Regulation of the Minister of Environment of 30 October 2003. These levels, while generally equivalent to the limit values defined in Recommendation 1999/519/EC, are much stricter. On the other hand, the methods of determination of the electromagnetic field are specified in Annex 2 to the Regulation of the Minister of Environment of 2003.

Places accessible to the public, in accordance with Art. 124(2) of the Environmental Protection Act, are defined as all places except those to which access by the public is prohibited or impossible without the use of technical equipment.

The admissible levels of electromagnetic field in the environment are expressed as the RMS value of the strength of the electric component of the field E expressed in [V/m] and the power density S expressed in [W/m^2], depending on the range of the radio frequency:

- for frequencies from 3 MHz to 300 MHz: E = 7 V/m;
- for frequencies from 300 MHz to 300 GHz: E = 7 V/m or S = 0.1 W/m^2.

The limit values indicated in the Regulation of the Minister of Environment of 2003 and the reference levels defined in Recommendation 1999/519/EC, for frequencies in which typical mobile telephony network base stations operate, are shown in Tab. 2.

A coparison, in the relevant radio frequency ranges, of the limit values set in the Regulation of the Minister of Environment of 2003 with the reference levels set forth in Recommendation 1999/519/EC (e.g. field strength E), leads to the conclusion that the national legislation aimed to protect the environment against electromagnetic fields is much stricter than the European requirements.

Act on the Inspection for Environmental Protection

The Act on the Inspection for Environmental Protection defines, among other things, the tasks of the Inspection for Environmental Protection, the body appointed to check compliance with the environmental protection legislation and to study and assess the status of the environment.

Monitoring of compliance with environmental protection legislation, in accordance with Art. 2(1)(1) of the Act, including study and assessment of the status of the environment, is carried out by the Inspection for Environmental Protection, as a part of planned inspections of entities that use the environment. According to Art. 17(3a) of the Act on the Inspection for Environmental Protection, upon a justified request of a local authority, the provincial environmental protection inspector is required to carry out an inspection that is not included in the inspection plan of the Inspection for Environmental Protection concerning the electromagnetic field emitted from a radiocommunication installation, including as a part of interventional tests.

Tab. 2. Limits and reference levels: field strength E and power density S for typical frequencies used in mobile telephony networks.

Frequency [MHz]		800	900	1,800	2,100	2,600
Field strength E [V/m]	Reference level according to Recommendation 1999/519/EC	38.9	41.3	58.3	61.0	61.0
	Limit value according to the Regulation	7.0				
Power density S [W/m^2]	Reference level according to Recommendation 1999/519/EC	4.0	4.5	9.0	10.0	10.0
	Limit value according to the Regulation[11]	0.1				

11 Regulation of the Minister of Environment of 30 October 2003, op. cit.

According to Art. 2(1)(2) of the Act, one of the tasks of the Inspection for Environmental Protection is to carry out state environmental monitoring, in particular:

a. development and implementation of multi-annual strategic state environmental monitoring programs and implementing state environmental monitoring programs;
b. collection of information on the environment in the scope included in the state environmental monitoring programs;
c. processing of collected information on the environment and performance of assessments of the status of the environment;
d. preparation of reports on the state of the environment;
e. participation in international exchange of information about the status of the environment, including coordination of cooperation with the European Environment Agency mentioned in Regulation 401/2009 of the European Parliament and of the Council (EC) of 23 April 2009 on the European Environment Agency and the European Environment Information and Observation Network (OJ EU L 126 of 21 May 2009, page 13).

The implementing legislation to the Act on the Inspection for Environmental Protection, which regulates the issues related to the duties of the IEP bodies, including performance of the state environmental monitoring and collection of data in the Information Technology System of the Inspection for Environmental Protection "Ekoinfonet," is:

- Regulation of the Minister of Environment of 12 November 2007 on the scope and methods of periodic tests of electromagnetic fields levels in the environment, specifying the method of selection of the measurement points, the required frequency of measurements, and the methods of presentation of the measurement results;
- Regulation of the Minister of Environment of 21 September 2015 on the information technology system of the Inspection for Environmental Protection "Ekoinfonet," specifying the scope of the data collected in the "Ekoinfonet," including the data submitted by provincial environmental protection inspectors, the data pertaining to studies and assessments of the status of the environment with regard to the electromagnetic field level and compliance with the environmental protection legislation with regard to inspection of entities that use the environment.

Act on making accessible information about the environment and its protection

Issues related to the principles and the mode of conduct with regard to making accessible to the public information about the environment and its protection, and the indication of the public authorities that are competent in this area are governed by the Act on making available information about the environment and its protection, participation of the public in environmental protection, and environmental impact assessments.

The implementing legislation to this Act is the Regulation of the Minister of Environment of 23 November 2010 on the method and frequency of updating of environmental information, specifying the method, the minimum scope, and the form of making information available, and the frequency of updating the information made available. This concerns the results of, among other things, periodic tests of the levels of electromagnetic field in the environment, carried out within the framework of the state environmental monitoring, and the list of areas where the admissible levels of the electromagnetic field have been found to be exceeded.

III.3

Methods of measurement of the electromagnetic field

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Measurement of electromagnetic field levels in the environment are subject to applicable legislation. To ensure the highest level of performance of those measurements, which would guarantee their quality and compliance with applicable legislation, Art. 147a of the Environmental Protection Act indicates accredited laboratories, supervised in Poland by the Polish Center for Accreditation (PCA), as the only entities authorized to perform electromagnetic field measurements in the environment.[1]

In this case, measurements are performed for the following physical quantities that describe electromagnetic fields (EMF):

- the strength of the magnetic component of the field H, expressed in amperes per meter [A/m];
- the strength of the electric component of the field E, expressed in volts per meter [V/m];
- the power density of field S, expressed in watts per square meter [W/m^2].

The parameter characterizing the impact of the electromagnetic field with frequencies generated by antenna installations of base stations is usually assumed to be the so-called RMS value of the electric field E [V/m], calculated as the geometric mean, according to the following formula:

$$E = \sqrt{E_1^2 + E_2^2 + E_3^2 + \ldots + E_N^2} \; ,$$

where: E_1, E_2, E_3, E_N are the measured or calculated RMS values *N* of the components of the electric field present in a given location.

Measurements of the electromagnetic field in the environment should be performed using specialized measuring equipment, the performance characteristics of which are affected by the properties of its two basic parts: the measuring antenna and the electric field meter.

The devices used for EMF measurements should be suitable for the measurement task (in terms of frequency range and levels to be measured) and used in the conditions specified by the manufacturer, and must have a current calibration certificate drawn up in accordance with the requirements of EN ISO/IEC 17025.

Good laboratory practice indicates that a kit for measuring radio-frequency and microwave electromagnetic fields should:

- be a portable instrument, with autonomous power supply and suitable for outdoor operation (with an impact- and dust-resistant enclosure);
- enable measurements of the EMF produced by antenna installations of radio systems that are in general use in national mobile telephony networks and presentation of measurement results in a form allowing their extrapolation to values

1 Act of 27 April 2001 – Environmental protection law (Journal of Laws of 2017, item 519).

corresponding to “worst case” situations, as required by the Regulation of the Minister of Environment[2].

The antenna of the measuring instrument, in the frequency ranges used by base station transmitters, should have isotropic characteristics, i.e. ones that guarantee uniform reception of signals from all directions. This recommendation is applied according to:

- the location of the measurement points on the main directions of emission of the antennas of the tested base stations;
- the polarization of the antennas of the tested base stations;
- the occurrence of propagation phenomena, especially formation of reflected waves.

According to Annex 2 to the above-mentioned Regulation, EMF levels should be measured in good weather (in practice: at above zero temperature and without precipitation), in so-called places accessible to the public (i.e. everywhere where presence of people is not forbidden or impossible without specialized equipment), and in such a way that the process of measurement itself does not disturb the results obtained (e.g. by hindering the propagation of electromagnetic waves emitted by the base stations). During the measurement, the antenna of the measuring instrument should be moved along a vertical line (in the measuring verticals) at heights between 0.3 m and 2 m above the ground surface or above another surface.

As follows from the same Regulation, in Poland the maximum values should be assumed to be the result of electromagnetic field measurements. Averaging of electromagnetic field measurements should not be performed, neither in time, nor in space. Consequently, the restrictions imposed in Poland on the method of determination of the levels of the electromagnetic field in the environment, which take into account the so-called “worst cases” – i.e., in reality the practically non-existent situation of simultaneous operation of all devices producing electromagnetic field with maximum power – are many times more severe than the restrictions adopted for direct application in most of the member states of the European Union.

Measurements of the electromagnetic field in locations accessible to the public are associated with their position in relation to base station antennas. For the sake of the quality of the measurements, it is immensely important to take the measurements in the so-called far field zone (see article I.3. on page 22). It is in that zone that regular citizens are present in most cases. Examples of the reference values for the distances defining individual zones of the electromagnetic field depending on the frequency (f) and the physical dimensions of the antennas (D) are in Tab 1.

Tab. 1. Example values of the zones of the electromagnetic field

System	Frequency f [MHz]	Antenna size D [m]	Far field d [m]
GSM 900	942.5	2.4	36.2
GSM 1800	1,842.5	1.5	27.6
UMTS 900	947.5	2.4	36.4
UMTS 2100	2,140	1.2	20.5
LTE 700	773	2.6	34.8
LTE 800	806	2.4	30.9
LTE 1800	1,842.5	1.5	27.6
LTE 2100	2,140	1.2	20.5
LTE 2600	2,655	0.8	11.3

Fulfillment of the conditions for the measurements in the far field zone requires taking into account a number of important parameters, such as installation height of the antennas and their location in relation to places accessible to the public, antenna tilt angles (so-called "tilt"), and azimuth angles.

Annex 2 to the aforementioned Regulation requires the so-called broadband measurements to be carried out.

The commonly used method of **broadband measurement** in the surroundings of a base station enables, among other things, determination of the RMS value of the electric component of the field. The result of the broadband measurement essentially consists of all signals received by the

2 Regulation of the Minister of Environment of 30 October 2003 on the admissible levels of electromagnetic fields in the environment and the methods of checking the observance of these levels (Journal of Laws, item 1883).

measuring antenna in the frequency range defined by its design, but it is not possible to identify the component frequencies.

Of note is the fact that the result of the broadband field measurement, in a given location, of the field produced by base stations operated in digital system networks is randomly variable, as it depends on the telecommunication traffic load on the base station. Thus it is not possible to determine directly from it, without additional measurements and calculations, the maximum levels of electromagnetic field that may occur in the case of the maximum telecommunications traffic load on the base stations.

A more technologically advanced instrument that enables performance of **selective measurements in terms of frequency** makes it possible to determine the field strength in a precisely defined frequency range. This enables identification of the frequency components of the measured field, including e.g. identification of the network in which the station that generates the field operates.

The results of the measurements, both broadband and for selected frequencies, reflect the strength of the electric field present in the surroundings of the base station in the course of its normal operation.

W in the case of digital radiocommunication systems, such as UMTS and LTE, the power of the transmitters delivered to the base station antennas depends on the user-generated telecommunications traffic load on the base stations[3], which means that, first, it is variable in time and, second, this variability is random. Thus, in reality, depending on the momentary traffic load on the station, the values of the strength of the field generated by the station change in time[4].

Thus, the results of both the measurements, both broadband and for selected frequencies, do not directly provide a basis for determination of the RMS value of the electric component of the field at the maximum load on a base station.

Therefore, in order to meet the requirements of the method of determination of the electromagnetic field described in Annex 2 to the Regulation, it would be necessary to include measurement corrections that allow for determination of the maximum values of the strength of the electromagnetic field emitted by a base station at the time of the highest telecommunications traffic load.

The Regulation does not specify the method of determination of such corrections. In this case, therefore, it is necessary to use the relevant technical standards that contain specific provisions that help establish the requirements that should be used when determining the electromagnetic field levels in the surroundings of radiocommunication installations, including base stations, so that the provisions of the Regulation can be complied with.

This was sanctioned formally in the DAB-18 program published by the PCA in 2017[5], which concerns accreditation of test laboratories that perform measurements of electromagnetic fields in the environment. The DAB-18 program provides that, for measurements of the electromagnetic field in the environment, the measurement methods described in the Regulation should primarily be used: moreover, it recommends using a number of technical standards that are appropriate for the scope of the tests performed. An example is the PN-EN 62232:2018-01 standard[6]. This standard describes, among other things, the methods of extrapolation of results to peak traffic conditions in the networks for different systems, including UMTS and LTE.

These methods, which apply to frequency-selective measurements in terms of code, refer to

3 National Institute of Telecommunications. "Pilot studies and analyses concerning the admissible limits of electromagnetic fields (EMF)," Annex 1. "Measurement methodology." Warsaw, December 2016.

4 Scuola Universitaria Professionale della Svizzera Italiana, Dipartimento Tecnologie Innovative, Alta Frequenza. "Basis for a UMTS measurement recommendation." Project 08R2-HFumts, 30 April 2004; Federal Office of Metrology METAS, Section Electricity. "Technical Report: Measurement Method for LTE Base Stations." METAS-Report no. 2012-218-808, May 3, 2012.

5 Polish Center for Accreditation, "Accreditation program for test laboratories performing electromagnetic field measurements in the environment DAB-18." Edition 1, Warsaw, 2 February 2017.

6 PN-EN 62232:2018-01 – Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure.

A seemingly relatively simple measurement task turns out to be a very complex process, which can result in numerous errors (e.g. overestimation of results) if due diligence is not ensured.

a theoretical situation of maximum telecommunication traffic load on the base station, which is a situation where all resources of the station are used simultaneously (all available systems in all available frequency bands, with simultaneous operation at the maximum power).

In practice, due to the advanced dynamic resource allocation algorithms (see article I.6. on page 40), the probability of this situation is close to zero. Therefore, on the one hand, it could be said that the measurement results are overestimated and, on the other hand, it is necessary to take into account the requirements of the Regulation concerning performance of measurements during the operation of the base station in most unfavorable conditions in terms of environmental impact.

Consequently, in order to properly measure the electromagnetic field, it is necessary, as a minimum, to:

- have an instrument with the appropriate measuring range and a valid calibration certificate;
- make the appropriate settings to the instrument;
- know and take into account the technical parameters of the tested base station and the base stations located in its immediate vicinity;
- select appropriate measuring locations that are accessible to the public and, at the same time, where maximum field levels are to be expected;
- keep the recommended (also by the manufacturer of the instrument) environmental conditions for the measurement in terms of temperature, humidity, and precipitation;
- take into account the impact of possible interfering factors such as people or buses passing by, metal structures in the immediate vicinity, etc.;
- based on the measurements performed during normal operation of the base stations, determine, by means of the extrapolation method, the maximum levels corresponding to the "worst case" situation described in the Regulation.

The numerous factors indicated above are sources of uncertainty for the measurement and form the uncertainty budget, which is usually estimated at a 95% confidence level. One must keep in mind that there are no ideal measurements and that every measurement, not only of the electromagnetic field, is:

- performed with a finite accuracy, which means that it is always (more or less) inaccurate;
- distorted by the impact of various factors that create the measurement uncertainty.

Consideration of the uncertainty of measurement should be viewed as positive as it creates a certain interval in which the result of the measurement fits with a certain probability.

The measured electric field strength values and the calculated RMS (root mean square) values of the electric field strength, taking into account the estimated expanded uncertainty of measurement (95% confidence interval), are subject to conformity assessment by way of comparison with the permissible electric field strength value, as defined in the Regulation.

Due to the conditions described above, an apparently relatively simple measurement turns out to be a very complex process, which may result in numerous errors (e.g. overestimation of the results) and may lead to serious consequences. As this is a regulated area, this confirms the validity of the obligation to perform EMF measurements in the environment by accredited laboratories, introduced in Art. 147a of the Environmental Protection Act.

Tab. 2 shows some differences between the methods for checking the observance of the

Tab. 2. Examples of methods of measurement complying with the Regulation of the Minister of Environment of 2003 – theory and practice

Measurement parameters	Theory	Practice
Working conditions of the base station	Measurements should be performed taking into account the "worst case," i.e. operation of all equipment that generates electromagnetic fields with maximum power.	Measurements are performed by configuring the base station to operate in a test mode (simulating the most unfavorable conditions from the environmental point of view) or during normal operation of the base station, using appropriate measurement corrections that enable extrapolation of the results to the most unfavorable values from the environmental point of view.
Measurement conditions	Measurements should be performed in the recommended conditions concerning temperature, humidity, precipitation, and with limited impact of factors that could interfere with the measurement, such as people or buses passing by, or metal structures in the immediate vicinity.	Measurements should be performed with due care and caution by people who are trained and experienced: a developed measurement uncertainly budget taking into account multiple sources of uncertainty should be used.
Measurement method	It is recommended to perform broadband measurements, the results of which consist of all signals received by the measuring antenna in the frequency range defined by its design, but it is not possible to identify the component frequencies of the measured field.	Use of selective measurements in terms of frequency, which enable determination of the field strength values in a precisely defined frequency range, and measurements for selected frequencies in terms of code; the results of the measurements for selected frequencies in terms of code refer to a theoretical situation of a maximum telecommunication traffic load on the station.

admissible levels of electromagnetic fields in the environment, which are specified in the aforementioned Regulation, and the methods used in practice that ensure the required compliance with the Regulation.

Measurement with the use of an exposimeter

A possible supplement to the measurements carried out by accredited laboratories is measurements carried out individually by citizens with the use of so-called exposimeters, incorrectly associated with and sometimes also called dosimeters.

A dosimeter is an instrument used to measure the dose of ionizing radiation or of radioactive activity of preparations. A dosimeter measures the dose absorbed by the body in a certain time, which is subject to accumulation. The radio-frequency electromagnetic field is non-ionizing and there is no cumulative effect; consequently, there is only exposure and no dose. Hence the correct name is "exposimeter" and not "dosimeter." The use of the name "dosimeter" can lead to misunderstandings and incorrect equating of the radio-frequency electromagnetic field with ionizing radiation, which is not true.

An exposimeter records individual exposure to the electromagnetic field (EMF) correlated with a GPS location. Once appropriately programmed, the exposimeter can automatically measure the electric component E [V/m] of the electromagnetic field and record the results. It enables individual measurement of the electromagnetic field in the environment, e.g. directly at the place of residence. Used properly, it can be an excellent tool for verification of the level of the electromagnetic field.

One should keep in mind, however, that an exposimeter is not a professional measuring instrument, it is often not calibrated, and does not have an estimated measurement uncertainty budget. In this regard, it should be treated as a **qualitative indicator** rather than a quantitative one. Moreover, there is still a critical problem with the correct use of exposimeters. Taking into account the impact of disturbing factors (e.g. closeness of the measuring person's body, metal bodies, sources of temporary emissions that falsify the measurement, such as those resulting from the exposimeter being put in close proximity to a microwave oven) on the measurement results, the recorded results must be treated with caution and the measurements should be performed with the awareness of the physical phenomena associated with propagation of electromagnetic waves. It therefore seems necessary to properly train exposimeter users.

Simulation of electromagnetic field distributions

A possible alternative method to measurement of the electromagnetic field in the environment is simulation of field distributions. Mathematical modeling is always auxiliary, but eliminates the need for measurements when simulations indicate that there are sufficient margins compared to the applicable limit values.

When using simulation software, it should be noted that the mathematical model normally makes some generalizations and simplifications, taking into account elements that are the most important for a given process or phenomenon. Application of the modeling of electromagnetic field distributions must, therefore, always take into account pessimistic assumptions specific to the "worst case." As measurements of the electromagnetic field are performed at a specific point in time, in a specific actual situation, and in a dynamically variable radio network, the measurement result is also variable – depending on the time of the day, the season of the year, the weather, and the traffic in the networks. Consequently, the simulated values of the electromagnetic field should always indicate the maximum values that can be reached during the measurement and should not indicate in any case values that are lower than the later measurement. This allows for effective implementation of the commissioning procedures for base stations, also without the need for measurements, when simulations indicate, for example, that in locations accessible to the public the simulated values of the electromagnetic field do not exceed a certain threshold (i.e. e.g. 70% of the limit value). Such solutions are already practiced in some countries: e.g. in Switzerland and in France, where there is no requirement to measure the electromagnetic field when a simulation analysis shows that the threshold defined by the administration is not exceeded.

However, the final criterion for assessment of safety and of whether or not the electromagnetic field limit values are exceeded is the results of accredited measurements performed in situations of uncertainty or specific expectations of the public.

Currently, the National Institute of Telecommunications (NIT) and the Ministry of Digital Affairs is carrying out a project aimed at building and making available an information technology system for radio installations that generate electromagnetic fields which covers the entire country (SI2PEM). This system will enable, among other things, precise estimation of continuous EMF distributions based on measurements and simulation analyses of the resultant EMF values on the basis of developed mathematical and engineering models. More information about the SI2PEM system can be found in the next article.

III.4

Measurements of the electromagnetic field in Poland and worldwide

Rafał Pawlak, Barbara Regulska

The beginnings of regular measurements of the electromagnetic field in the environment in Poland date back to 2001, when both the state environmental monitoring and the measurements performed by operators of radiocommunication installations became legally in the Environmental Protection Act[1]. Initially, measurements were carried out on behalf of the Chief Inspectorate of Environmental Protection (CIEP) by:

- the Technical Institute of the Air Force – in the years 2001–2003;
- the Energy Institute – in 2005;
- the Central Institute for Labor Protection – in 2006; and
- the Ergon Environmental Testing Laboratory – in the years 2014–2015.

At the same time, starting from 2004, measurements were started by the Provincial Inspectorates of Environmental Protection, and since 2008 measurements have been carried out in a uniform way for in entire country.

The entities performing the measurements, the objectives, the mode, and the types of measurements are specified in: Environmental Protection Act and Act on the Inspection for Environmental Protection[2]. Measurements of electromagnetic fields in the environment are performed by:

- operators of radiocommunication installations that emit electromagnetic fields;
- a provincial environmental protection inspector, to assess electromagnetic field levels in the environment and to observe the changes, as a part of the state environmental monitoring;
- bodies of the Inspection for Environmental Protection, as a part of planned inspections of entities using the environment;
- a provincial environmental protection inspector, upon a justified request of a local government body, as a part of activities not covered by the inspection plan of the Inspection for Environmental Protection, including the so-called intervention studies.

Starting from 2016, at the initiative of the Ministry of Digital Affairs, the National Institute of Telecommunications (NIT) has been carrying out **measurement campaigns** that include, among other things, measurements of the electromagnetic field surrounding antenna installations of base stations.

1 Act of 27 April 2001 – Environmental protection law (Journal of Laws of 2017, item 519).

2 Act of 20 July 1991 on the Inspection for Environmental Protection (Journal of Laws of 2016, item 1688).

Measurements performed by installation operators

Operators of radiocommunication installations whose so-called equivalent isotropically radiated power is not less than 15 W, which emit an electromagnetic field at frequencies between 30 kHz and 300 GHz, according to z Environmental Protection Act, are required to:

- measure the levels of the electromagnetic field in the environment immediately after starting to use the installation and each time when the operating conditions of the installation change, if these changes may result in a change of the electromagnetic field levels;
- submit the results of the measurements to the provincial environmental protection inspector (from 1 January 2019 to the chief environmental protection inspector) and to the provincial sanitary inspector.

The measurements are performed in compliance with the Regulation of the Minister of Environment of 30 October 2003, pursuant to Art. 147a of the Environmental Protection Act, by accredited laboratories.[3]

The measurement are submitted on paper.

Access by citizens to the documentation of installations that generate electromagnetic fields, including the results of electromagnetic field measurements, requires a written request submitted to local environmental protection departments of municipal authorities. This is regulated by the Act of 3 October 2008.[4]

Measurements performed by installation operators – measurement results

Currently there are no synthetic compilations of the results concerning electromagnetic field strength levels from measurements conducted by operators of radiocommunication installations. Random knowledge in this regard could be gained from the results of studies of the status of the documentation of installations that generate electromagnetic fields, including reports from measurements carried out in 2016 by the NIT as a part of the pilot measurement campaign using the example of Cracow and Rzeszów.

These studies were aimed, among other things, at indicating the installations for which the measurement reports indicated presence of electromagnetic field values of not less than 50% of the limit value specified in the Regulation adopted in 2003. It was found that the limit value of 7 V/m was not exceeded in the surroundings of any of the installations, while 50% of this value was slightly exceeded:

- in Cracow, in 62 installations out of the 366 installations analyzed (17%);
- in Rzeszów, in 24 installations out of the 80 installations analyzed (30%).

At the same time, steps were taken to **ensure public access to the results of electromagnetic field measurements** (also to presentation on maps) with information about the location of the radio transmitters, the types and parameters of the equipment used, and the parameters of the antenna systems. Such functionalities were to be provided by the newly designed Information System for Installations that Generate Electromagnetic Radiation (SI2PEM).

State environmental monitoring

Monitoring of electromagnetic field level in Poland is carried out within the framework of national environmental monitoring, according to the national program of State Environmental Monitoring[5] and the provincial programs prepared on its basis.

Since 2008, Provincial Inspectorates of Environmental Protection have been carrying out monitoring of the electromagnetic field in three-year cycles

3 Regulation of the Minister of Environment of 30 October 2003 on the admissible levels of electromagnetic fields in the environment and the methods of checking the observance of these levels (Journal of Laws of 2003, item 1883).

4 Act of 3 October 2008 on provision of information about the environment and its protection, involvement of the public in environmental protection, and environmental impact assessments (Journal of Laws of 2017, item 1405).

5 See: http://www.gios.gov.pl/pl/stan-srodowiska/pms.

in a uniform way for the entire country. In 2016, the third measurement cycle for the years 2014–2016 was completed. Currently, the State Environmental Monitoring Program for 2017–2020 is being implemented and provincial programs are being developed on its basis.

The basic assumption of electromagnetic field monitoring is **tracing of the levels** of electromagnetic fields from man-made sources in the environment, with reference to the limit values for locations accessible to the public.

Measurements are carried out based on the Regulation of the Minister of Environment of 12 November 2007[6], which sets forth the method of selection of the measurement points, the required frequency of the measurements, and method of presentation of the results of the measurements.

In the territory of each of the provinces, **a network of 135 measurement points** is designated, in which **measurements are performed in a three-year cycle (45 points each year)**. The points are distributed evenly in each province in **three types of areas** accessible to the public:

- in central residential districts of cities with the population of more than 50,000;
- in other cities;
- in rural areas.

The measurements are performed in a **continuous manner for two hours**, with sampling interval of at least every 10 seconds, between 10.00 AM and 4.00 PM on business days. The air temperature must not be lower than 0°C, the humidity must not be higher than 75%, and there must be no precipitation. Electromagnetic field monitoring is performed by measuring the strength of the electric component of the electromagnetic field in the frequency range of at least 3 MHz to 3 GHz. The result is **the arithmetic mean of the measured values from a two-hour measurement** for the measuring point and the arithmetic mean of the averaged values for each type of area (15 points). The arithmetic mean of the areas z averaged values of electromagnetic field strengths obtained w 45 points of the three-year measurement cycle shall be reported every three years.

The results of the monitoring measurements of electromagnetic field carried out by the Provincial Inspectorates for Environmental Protection are submitted once a year to the Chief Inspectorate for Environmental Protection (CIEP). The CIEP conducts **annual and tri-annual assessments of electromagnetic field levels**[7].

Pursuant to Art. 28h(1) of the Act on the Inspectorate for Environmental Protection, an **information technology system of the Inspection for Environmental Protection "Ekoinfonet"** has been created, which is used to collect, store, process and make available data concerning compliance with environmental protection legislation and testing and assessment of the status of the environment.This system includes, among other things, **a database for monitoring non-ionizing radiation – electromagnetic fields named JELMAG**. All monitoring data collected in that database is used to prepare information about electromagnetic field levels in areas accessible to the public, including reports from monitoring and the aforementioned periodic assessments of electromagnetic field levels in the environment for entire country. Currently, access to the JELMAG database[8] is possible either by means of a special token, or at the offices of the CIEP/PIEP.

State environmental monitoring – measurement results

According to the latest report of the Chief Inspectorate for Environmental Protection, the Department of Monitoring, Assessment, and Forecast of the Status of the Environment prepared in November 2018 based on the results of measurements

6 Regulation of the Minister of the Environment of 12 November 2007 on the scope and the method of periodic testing of electromagnetic field levels in the environment (Journal of Laws of 2007, item 1645).

7 The results of the measurements and of the assessments of electromagnetic field levels in the environment are presented in the form of reports on the status of the environment posted on the website of the CIEP and the PIEP. See: http://www.gios.gov.pl/pl/stan-srodowiska/monitoring-pol-elektromagnetycznych.

8 The JELMAG database operates at: http://ekoinfonet.gios.gov.pl/eim.

performed by Provincial Inspectorates for Environmental Protection,[9] the level of electromagnetic field in the environment in Poland remains low.

The arithmetic mean of all the measurements performed by the PIEP inspectorates in 2017 was equal to 0.38 V/m, which is only 5.4% of the limit value. Broken down by type of area for which monitoring is conducted, the values of the electromagnetic field level are the following:

- for central residential districts of cities with the population of more than 50,000: 0.55 V/m;
- for other cities: 0.39 V/m;
- for rural areas: 0.21 V/m.

The measurements carried out by the Provincial Inspectorates for Environmental Protection in 2017 show that the average electromagnetic field strength did not exceed 0.55 V/m in large cities, 0.39 V/m in small towns, and 0.21 V/m in rural areas.

Average electromagnetic field strength in the environment obtained within the framework of the State Environmental Monitoring in 2017.

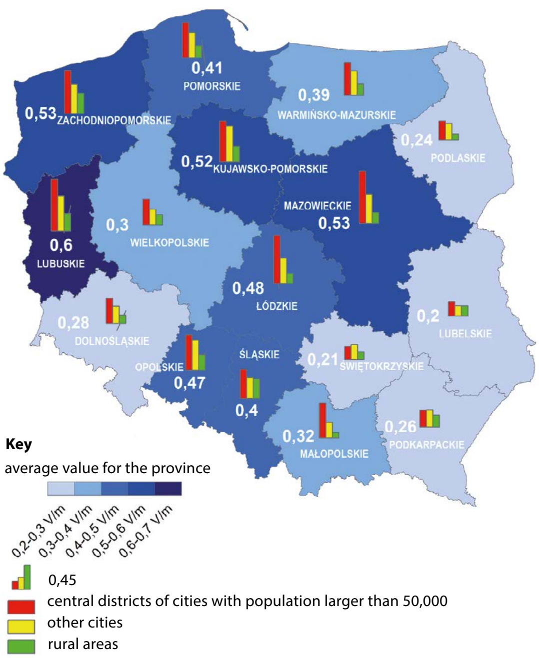

Fig. 1. Presentation of the results of the State Environmental Monitoring of 2017. Presentation by Katarzyna Moskalik, Department of Monitoring, Assessment, and Forecast of the Status of the Environment of the CIEP, 3rd International EMF Conference, 6 December 2018, Warsaw.

Electromagnetic field measurement campaigns

From 2016 onwards, the NIT has been implementing, at the initiative of the Ministry of Digital Affairs, **measurement campaigns** that include, among other things, measurement of electromagnetic field levels in the surroundings of antenna installations of base stations, which are intended to **assess the conformity of the results to the limit value**. The pilot electromagnetic field measurements completed in 2016[10] were aimed at:

- verification of whether, in locations accessible to the public, in the vicinity of antenna installations of base stations, the determined RMS value of the electric component of the electromagnetic field does not exceed the limit value of 7 V/m;
- checking and verification of the suggested measurement methodology recommended for use in future measurement campaigns.

The measurement campaign, completed in 2017 using the products and the experience of the pilot campaign, made it possible to perform **measurements at more base station locations** and to check

9 "Assessment of electromagnetic field level in the environment in 2017 – based on results of measurements performed by Provincial Inspectorates for Environmental Protection." Chief Inspectorate for Environmental Protection, Department of Monitoring, Assessment, and Forecast of the Status of the Environment, November 2018.

10 A report from the pilot studies and the analyses of electromagnetic field limits, together with information and educational materials, has been made available on the website of the National Institute of Telecommunications. See: pem.itl.waw.pl.

in practice the methodology of measurements **in the surroundings of 2.4 GHz and 5 GHz RLAN (radio local area networks) access points**. The measurement campaign of 2017 enabled, among other things, an analysis of the results of selective measurements, allowing precise identification and indication of sources of the recorded components of the electric field (frequency range, operator, system/service) if the results exceed the limit value.

On the other hand, in the measurement campaign completed in 2018, a total of **96 locations of mobile telephony base stations** were selected for the measurements, 6 locations in each of the 16 provinces. Measurements in the surroundings of 2.4 GHz and 5 GHz RLAN access points were performed for **32 schools**, two in each of the 16 provinces.

In the research conducted as a part of the 2017-2018 measurement campaigns, **a innovative methodology** developed in 2016 was used[11].

The broadband measurement results obtained in the measurement campaigns completed in 2017 and 2018, which reflected the electromagnetic field strength values in the environment during normal operation of the base stations, indicate that **the general public limit, except in a single case in 2017, was not exceeded**.

The detailed results of the electromagnetic field measurements carried out as a part of the measurement campaigns are presented **in reports, separately for each of the tested locations**. Moreover, cumulative measurement results, conclusions, and assessments from the campaigns are presented in annual **reports**[12].

There are also plans **to start work on the introduction of constant monitoring of** electromagnetic fields originating from radiocommunication installations for all mobile telecommunication (first in cities where the 5G network will be implemented), which will guarantee online access to current data to the public. One of the first steps on this path is to build the Information System for Installations that Generate Electromagnetic Radiation (SI2PEM).

The results of the broadband measurements performed in the course of the campaigns carried out in 2017 and 2018 indicate that the limit value in the environment is not exceeded, except for a single case from 2017.

Electromagnetic field monitoring systems worldwide

An analysis of the methods and principles of electromagnetic field monitoring used in countries of the European Union indicates **big differences in this respect**. Most countries have internal regulations for protection against electromagnetic fields. These regulations are based on Recommendation 1999/519/EC[13], and a large majority of them adopts **the limit values specified in this Recommendation**.

In EU countries, the supervisory and control bodies in the area of electromagnetic field testing are usually those involved in **healthcare, environmental protection, or infrastructure.** Sometimes, these tasks are performed in parallel by two or three different entities (e.g. in Portugal).

In most member states, as well as in Poland, measurements of electromagnetic field levels are

11 "Pilot studies and analyses concerning the admissible limits of electromagnetic fields (EMF)," Annex 1. "Measurement methodology." National Institute of Telecommunications, Warsaw, December 2016.

12 The test reports and maps showing the locations and measurement points, in which the limit values were found to be exceeded, are made publicly available among others on the website at: pem.itl.waw.pl.
In addition, as a part of the measurement campaign completed in 2018, the measurement results from all campaigns were shown in interactive maps, which enable using different filters and selecting the information to be displayed. These maps will also be made available on the above-mentioned website.

13 Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz). 1999/519/EC, *Official Journal of the European Communities*, L199/59, 1999.

carried out by accredited laboratories at the time of commissioning of new installations or when significant changes are made to them. On the other hand, in some countries (e.g. in Switzerland), **measurements are not required** when a simulation analysis shows that the admissible electromagnetic field level threshold defined by the administration is not exceeded. **Simulation analyses** are performed in such cases by operators using their own field distribution modeling software.

In addition to the measurements conducted at the time of commissioning of the installations or when major changes are made to them, in most countries (including in Poland), control and intervention surveys are sometimes carried out at the request of the public (e.g. in France). **Monitoring** is also conducted with a very different scope, using both permanent and changing (including mobile) measurement points. Similar measurement methodologies are used; in most cases, **broadband measurements** are performed and the result is assumed to be the mean value of the measurement in any 6-minute period, in accordance with the ICNIRP guidelines and Recommendation 1999/519/EC. The results of the monitoring are usually made public. **Various forms of presentation of the measurement results** are used: annual summary reports, tables, graphs with the limit values marked, maps containing data on the base stations, etc.

An analysis of the methods of measurement and monitoring of the electromagnetic field used worldwide indicates some directions for changes and development in this regard that could be implemented in Poland. The recommended development actions are indicated below.

- Start of work on a new measurement methodology that will take into account, among other things, the ICNIRP guidelines and the requirements set out in w Recommendation 1999/519/EC which introduced the determination of the mean value for a measurement conducted during any 6 minute period.
- Ensuring universal, easy, and clear access for citizens to relevant information about installations and results of electromagnetic field level measurements in the surroundings of mobile telephony base stations (such access is to be provided by the newly designed SI2PEM system).
- Start of work on (legal) standardization and uniformization of reports from measurements that are submitted by businesses or accredited laboratories together with notifications of new installations.
- Development of national guidelines and technical criteria for simulation analyses and introduction of a simulation analysis of electromagnetic fields as a tool to support network planning and to enable preliminary verification of fulfillment of the requirements. Imposing an obligation to perform measurements when the values obtained from the simulation would exceed a fixed threshold value (e.g. above 70% of the limit value).
- Start of work on the introduction of constant monitoring of electromagnetic fields originating from telecommunication installations for all mobile telecommunication (first in cities where the 5G network will be implemented), which will guarantee online access to current data to the public.

Information System for Installations that Generate Electromagnetic Radiation (SI2PEM)

One of the essential elements that ensure effective and efficient public control and monitoring of electromagnetic field sources establishing and making available a uniform information technology system allowing public access to technical data of installations and reports from measurements of electromagnetic field levels.

At the same time, there is no public and open system for monitoring and control of electromagnetic field emissions in Poland that would enable a comprehensive assessment of the total values of the electromagnetic field that constitute a superposition of the fields produced by different radiocommunication installations and an assessment of all the possible phenomena associated with occurrence of an accumulation of the electromagnetic field.

The National Institute of Telecommunications ant the Ministry of Digital Affairs started the project related to the Information System for Installations that Generate Electromagnetic Radiation (SI2PEM), whose objective is to build and make available an information system for radio installations that generate electromagnetic fields, that will cover the entire country and support the protection of the inhabitants against possible excessive impact of electromagnetic fields. The database to be created and operated within the framework of the newly designed SI2PEM system will contribute, among other things, to:

- ensuring unambiguity, completeness, and consistency of the data related to radio installations that generate radio-frequency electromagnetic fields and
- effective monitoring and reporting of radio-frequency electromagnetic field test results. Such reports will provide information on the available spare electromagnetic field levels compared to the legal general public limit value: this will enable more effective observance of appropriate electromagnetic field levels in the environment;
- facilitating access to relevant data on electromagnetic field levels: for citizens, administrations, businesses, scientists, etc.

At the same time, the activities carried out as a part of the proposed SI2PEM system will make it possible to increase the transparency of the decision-making process related to the issuance of relevant permits in this area by the relevant state authorities, as well as to improve this process in the upcoming era of 5G technology.

As mentioned earlier, the proposed SI2PEM will collect the available results of electromagnetic field measurements together with information on the location of radio transmitters, the types and the parameters of the equipment used, and the parameters of the antenna systems. This system, on the basis of parameters of broadcasting systems, mathematical models, and actual measurements, will also simulate electromagnetic field strengths. The data collected in the system will be made public in multiple formats, including presentation on maps.

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5

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IV. *5G technology*

5

Introduction

- The growing demand for telecommunication services stimulates the development of new technologies.
- The introduction of each successive generation of mobile technology has been associated with an increase in data transfer rates by several orders of magnitude, an improved connection quality, and an emergence of new functionalities.
- The currently used 4G technology has been used worldwide since 2009.

  - The 5G network will enable a number of new services, including the massive "Internet of Things" and smart cities.
  - The new technology will use low, medium and high-frequency bands, all of which have their advantages and limitations.
  - The popularization of the 5G network requires deployment of antenna infrastructure and implementation of new technological solutions.

- The 5G technology will find broad applications in many areas of the economy: the so-called Industry 4.0, as well as modern agriculture, and the service sectors.
- The faster and more reliable mobile communication technology will enable a revolution in, among others, healthcare (e-health), support for disabled people, and management of urban infrastructure.
- Entertainment and education will also benefit from new interaction possibilities and fast access to large data resources. New forms of remote competition and more personalized remote guides and translators will become possible.

  - New services, new professions, higher quality of connections, and savings are only some of the benefits of 5G for the ordinary citizen.
  - Businesses will gain more possibilities of automation and remote solutions, will save money by reducing business trips and fully implementing remote work chances.
  - It is estimated that the new technologies and services will increase the global GDP by approx. 7%.

IV.1
Cellular technology generations – introduction

The analyses described in this text have been co-financed by the National Center for Research and Development as a part of the project titled "Implementation of 5G networks in Polish economy 5G@PL" (Gospostrateg Program)

Mariusz Gajewski

Current mobile networks (4G LTE) have come a long way in evolution to meet the growing expectations of the players in the telecommunications market. New standards of mobile technology have been implemented approximately every decade. Let us take a quick look at this evolution.

1G: cells

The first mobile networks that operated based on a division into cells, i.e. areas controlled by individual base stations, were built in the early 1980s. The first networks were built in the USA (based on the system called AMPS – *Advanced Mobile Phone Syste*m), in Japan (1NTT system), and in the Scandinavian countries, which jointly developed the NMT (*Nordic Mobile Telephone* system), which was the first cellular system in Europe and the only one to provide coverage of several countries (the 1G mobile systems were not compatible). The system initially used the 450 MHz band but, after reaching its maximum capacity, an upgraded version using the 900 MHz band was launched. The Polish 1G mobile network was launched in 1992 under the name "Centertel" by the Polish Mobile Telephony company. The network was based on the NMT450i system – an upgraded version of the NMT450 system.

The 450 MHz band provided good coverage with the radio signal of a large area within a single cell. In this way, providing cellular network services along the coast and the motorways, and in large rural areas required fewer cells than in the case of networks operating in higher radio frequency bands.On the other hand, cell capacity calculated as the number of simultaneously served subscribers remained unchanged, which in areas of high population density resulted in lack of access to services as the number of subscribers increased. This is why operators also started to implement a version using the 900 MHz band, creating cells of smaller size.

1G networks used the FDMA (*Frequency Division Multiple Access*) principle. This means that for the duration of a call, the terminal (terminal device) received for its use a radio channel in the form of a part of the frequency band, typically 25 or 30 kHz. However, this method of radio channel use was inefficient because the channel was occupied for the duration of the entire call, regardless of whether the user was talking or not. With an increase in the number of phone calls initiated by successive users, the capacity of the base station was exhausted as the number of radio channels per base station remained constant.

The 1990s: 2G and roaming

The basis for the development of the second generation cellular network (2G), i.e. the GSM system (*Global System of Mobile*

Communications), was the aim that the network should enable the use of services by a much larger number of users than before. Moreover, the new standard was to be based on digital transmission of voice calls and to guarantee much better protection against eavesdropping and better call quality. A significant improvement was also supposed to be the compatibility of 2G networks built by different operators and, consequently, the possibility for subscribers to use roaming services, i.e. telecommunication services provided outside the home operator's network.

The standard describing the functioning of the GSM system was finalized by the *European Telecommunications Standards Institute* (ETSI) in 1991. Although initially the GSM system was only intended for Europe to operate in the 900 MHz band, later the 1800 MHz band was also included. For the USA, a version of the system working in the 1900 MHz band was developed.

Unlike 1G networks, in the 2G system, information is digitized before transmission. This enabled the use of mechanisms that reduced the amount of information and of a transmission method used by the user in the radio channel. The first mechanism is voice compression, whereby the compressed digitized voice call transmitted in the radio channel requires transmission of less data than in the case of an uncompressed signal. This procedure, although it leads to a perceived decrease in the quality of phone calls, significantly reduces radio channel utilization.

The second mechanism consists in division of the digital signal transmitted by users into parts and then their transmission in the shared radio channel of the same frequency. This is done in the so-called *timeslots*, which are periodically repeated transmission windows in which the user sends or receives data. Application of this access method, known as TDMA (*Time Division Multiple Access*), significantly increased the number of subscribers using radio access in a given frequency band.

Further work on the development of the 2G standard resulted in 1997 in the specification of the GSM system called Phase 2+, which included the HSCSD (*High Speed Circuit Switched Data*), the GPRS (*General Packet Radio Service*), and the EDGE (*Enhanced Data rates for GSM Evolution)* data transmission technologies. The first of the above technologies used the same radio channels that in the GSM system were used for voice transmission. This meant that timeslots were busy for the entire duration of the call, even when data is not being transmitted. The newer technologies (GPRS and EDGE), often referred to as 2.5G networks, introduced into 2G networks transmission with packet switching, i.e. transmission where users send and receive packet data by sharing physical channels. One of the consequences of this type of transmission is a different charging rule, based on the size of the transmitted data and not on the duration of the call when the data transmission took place, as in the case of the HSCSD technology.

3G: multimedia services

The third generation of mobile systems, which was used by operators in the first years of this century, used the 2.5G network concept in terms of packet data transmission; however, unalike the GSM system, the 3G system was to provide various services (audio and video transmission and packet data transmission) immediately.Consequently, this meant that the backbone network connecting the base stations had to be expanded However, the biggest changes, compared to the 2G network, were made in the radio part. The *International Telecommunication Union* (ITU), as an organization established to standardize and regulate the telecommunications and radiocommunication market worldwide, designated the following frequencies for use in 3G networks: 790–960 MHz, 1710–2025 MHz, 2110–2200 MHz, 2300–2400 MHz, and 2500–2600 MHz, some of which was used by GSM systems. 3G networks also used a radio access method different from that used in GSM networks, which enabled even more users and offered higher data rates. Although it was not possible to create a globally unified 3G system, a family of systems called IMT-2000 was defined, which could work together and offer similar capabilities. The family included the UMTS (*Universal Mobile Telecommunications System*) standard proposed by the ETSI and implemented by most operators worldwide. Patronage over the development of this and subsequent mobile network standards has been assumed

Myth:

The further away the base station is, the better, because the radiation is lower

The further away we are from the base station, the less radiation we are exposed to, which results directly from the phenomenon of damping of propagating electromagnetic waves. However, ensuring the availability of radio services requires a minimum level of radio signal power in the entire area. This can be achieved in two ways: by using a single, high-power base station or by using several base stations with much less power. Thus, exposures to radiation at the same distance from the base station may be completely different.

One should also be aware that transmitting antennas are most often installed high and the radio beam is shaped in such a way that radio waves propagate in a horizontal plane, with the signal being strongly damped in the direction down the antenna. This means that people who are at a short distance under the antenna are not exposed to high EMF values.

It should be noted that terminal devices (e.g. mobile phones) can often cause greater exposure to electromagnetic fields than base stations: although they have many times less radio power, they are in direct contact with the user. As a result, the exposure to EMF from the terminal device is higher than from the base station. What is more, terminal devices use algorithms that change the power of the transmitted radio signal based on the power of the signal received from the base station: the weaker the signal received, the higher the power of the signal transmitted from the terminal. Thus, paradoxically, a large distance from the base station usually means greater exposure to electromagnetic radiation for mobile network users.

by the *3G Partnership Project*, a group of the largest standardization organizations in the world of radio telecommunications.

4G: the age of smartphones

The continuing development of Internet services has made increasing demands on the efficiency of data transmission. As a result, further development of mobile technologies has focused on development of a standard that would increase the speed and reliability of data transmission, based on the existing 3G network infrastructure. As a result, at the end of 2008, the 3GPP consortium developed the first version of the 4G LTE network standard, which initially operated in the 1800 MHz band, with channel band width from 1.4 MHz to

20 MHz, which enabled improved coding, optimized data transmission speeds, and higher efficiency. In addition to the improved transfer capability, the 4G LTE standard is characterized by a low incidence of downtime and transfer errors and a significantly lower latency compared to 3G.

Transmission in a 4G network supports speeds up to 150 Mbps for data transmission to the end user, and packets are transmitted with the speed of at up to 50 Mbps. Due to that, the 4G LTE network provides users with fast wireless Internet access, personalized telephony, and use of mobile broadband applications for mobile phones, laptop computers, and other electronic devices. Many foreign and domestic operators have implemented in their networks mechanisms that extend the capabilities of the LTE technology. The LTE-Advanced technology, which uses the so-called bandwidth aggregation, i.e. combination of several carrier frequencies into one channel of a larger bandwidth, enables data download speeds of up to 1 Gb/s and upload speeds of up to 500 Mb/s.

IV.2

Assumptions and goals, planned parameters of 5G

Waldemar Latoszek, Konrad Sienkiewicz

By using new technological solutions, the 5G network meets the growing requirements of users, including the growing number of devices and the quality requirements imposed by applications. This is an extension of today's 4G network and is characterized by solutions that can both handle the quickly increasing quantity of data transmitted and meet the demand for data exchange between the increasing number of "Internet of things" devices.

As with each version of mobile networks implemented so far, it is assumed that until the range and the capabilities offered by the existing cellular network are provided, the 5G network will initially function together with the existing networks.

Three areas of application

There are three main application scenarios that will be of particular importance to users in the case of the emerging 5G network. These scenarios expand the existing areas of use of mobile networks and distinguish the 5G network from the previous generations.

The *enhanced Mobile Broadband* (**eMBB),** which provides fast Internet access (on the order of 1 Gbps), will be the main feature distinguishing this generation of networks from the previous ones, especially at the initial stage of its implementation. This advantage of 5G will result in improved performance and quality of communication in the society. As a showcase of an application of 5G, it will include services based on delivery of high-resolution multimedia, attractive forms of communication (e.g. video calls and augmented and virtual reality), as well as smart city services (including video materials from high-resolution cameras).

The second area is based on *massive Machine Type Communications* (**mMTC**), in which 5G will offer connecting a very large number of devices with low power consumption, known as "Internet of Things" devices (IoT). Using the cellular network for communication, these devices exchange data in an asynchronous manner. This scenario assumes that many types of devices can be connected, but their common feature will be occasional use of the cellular network and exchange of small data volumes.

Ultra-Reliable Low Latency Communications (**URLLC**) will be a technology that will provide a communication delay below 1 millisecond to enable data exchange over a cellular network for critical ap- plications (e.g. control of drones). In the previous generations of cellular networks, the achieved delay values were greater and, in the 3G network, equal to approx. 100 milliseconds, and in the 4G (LTE) network, equal to approx. 30 milliseconds.

Backbone network and radio access network

New technologies and new radio frequency resources will be used to provide the network parameters specified above. Like in the previous generations of cellular networks, the 5G network will also consist of two basic components: the backbone network and the radio access network. However, while in the previous generations of cellular networks the technological changes were mainly related to the radio access network, in the case of 5G both these network segments have been changed significantly.

As in the case of each next-generation network implemented so far, 5G will initially operate together with the existing networks.

The introduction of the 5G network involves a number of new technological solutions that will significantly change the current model of use of telecommunications networks. Such technologies undoubtedly include those related to virtualization and programmability of networks, which will ensure a high degree of flexibility of the 5G network and allow introduction of network segmentation. This consists in that several different layers/areas can be created in a single physical network, each having its own set of settings tailored to the specific service. Segmentation is performed using the *Network Functions Virtualization* (NFV) technology and the *Software Defined Network* (SDN). It should be emphasized that the use in 5G networks of the SDN technology, i.e. introduction of network programmability and the network abstraction approach, changes the existing paradigm of design and maintenance of the network by introducing a clear division into the control plane and the data transfer plane, which are independently scaled, thus simplifying the management of the network and enabling better organization of resources and services. At the same time, the NFV technology enables the network functions (so far performed using specialized equipment) by software modules installed on standard commercially available servers. In addition, these technologies enable dynamic allocation of network resources according to application needs, increasing operational flexibility and simplifying the deployment of services.

One of the major new 5G network technology solutions in the backbone network segment is the MEC (*Multi-access Edge Computing)* technology, which provides the ability to process and store user application data in the base station of the 5G network. This technology was developed in order to solve a number of problems occurring in cellular networks, especially related to high delays associated with central data processing and with a long distance between data processing systems and users. The MEC technology provides new opportunities for application suppliers and operators. They can develop innovative services that have not yet been available due to the limitations of the telecommunications network. An example is the *Tactile Internet* services which include scenarios of use where people remotely control both real and virtual objects, based on a sensory signal and other feedback such as images and sounds.

In the case of the radio access network segment, as in previous-generation networks, the 5G access network also consists of infrastructure that provides terminal devices with access to the cellular network (including base stations, antennas, masts, etc.). The area covered by the radio signal from individual base stations is also divided in a similar way, i.e. into cells. On the other hand, in 5G networks, a much greater role than in the existing cellular networks will be played by cells of smaller sizes.Depending on the local conditions (e.g. user density) microcells (range up to 2 km) will be used in city centers and pico-cells, with the range from about a dozen to a hundred meters, will be used as local access points at such places as stadiums.

Three frequency bands

According to the current state of 5G network standardization, three frequency bands are planned to be used for its operation: low, medium, and high.

The designation of the specific bands depends on its characteristics, including in particular two factors: the way the signal propagates (radio propagation) and the capacity of the spectrum resources. The first of the factors is related to the physical properties of electromagnetic waves and determines the achievable ranges in radio transmission in changing weather conditions and radio coverage of areas that are hard to reach (e.g. building interiors). The second factor is identified with the available amount of radio spectrum in a given frequency range that can be used in 5G networks. One must keep in mind that high bit rates also require a wide radio bandwidth which, being a limited resource, is rationed and its use must also include radiocommunication applications other than 5G networks, e.g. television broadcasting, radio communication of home automation devices, etc.

In the 5G network system, the following three frequency ranges are assumed to be used first:

- 694-790 MHz (700 MHz band);
- 3400-3800 MHz (3.4-3.8 GHz band); and
- 24.25-27.5 GHz (26 GHz band).

The **700 MHz band** is characterized by good signal propagation and relatively low attenuation (signal absorption by various obstacles), which provides the possibility to cover large areas. This band can be used for mMTC services, i.e. massive communication between machines. Due to the impossibility of using the mMIMO – which would increase the cell's capacity – the band itself would not be able to provide broadband Internet access to mobile device users (eMBB service). However, it can be used together with the following bands, which have large spectral resources. With this type of operation, the transmission quality in the direction from the user to the base station (i.e. "uplink") is improved.

The **3.4-3.8 GHz** band enables the use of mMIMO, and at the same time is a compromise between propagation and capacity resulting from the spectral resources, especially in connection with the 700 MHz improving the "uplink" connection. This band would be used to build the covering layer for eMBB services for several largest Polish cities, including the major roads between them. This band can also be used to introduce services that require reliable transmission and particularly low latency (URLLC) in applications requiring the transmission of particularly large data volumes, e.g. high-resolution images for medical or navigation purposes (see the infographics on page 122).

The **26 GHz band** is limited in terms of area of use, especially due to fulfillment of the requirements related also to transmission in the direction from the user to the base station ("uplink" connection). It can be used, among others, for broadband hot spots and for pico-cell cMTC/URLLC applications. Due to its large capacity and the possibility of allocating large spectrum resources, this band can also be considered for providing Internet access as a part of the Fixed Wireless Access service.

More antennas and more cells mean that the power required to transmit signals will be correspondingly lower, also in the case of terminal devices, such as smartphones.

New technologies

The most important new 5G technological solutions in the area of radio networks include: 1) Massive MIMO (*Massive Multiple Input, Multiple Output*); 2) radio *beam forming*; 3) Multi-RAT (*Multi-Radio Access Technology*).

While sector antennas were used most often in the previous solutions, 5G networks will use antennas in the massive MIMO technology. This is an extension of the MIMO technology, which is currently used, among others, in LTE-Advanced networks. In the MIMO technology, each antenna consists of several components, which enables a more stable transfer and a higher data transfer rate, while allowing more users in a single cell area. Massive MIMO, on the other hand, assumes the use of antennas with a much larger number of components (e.g. 64 x 64), which will significantly increase the effectiveness of communication in the served area.

Another element enabling an increase of the efficiency of radio transmission in 5G networks is the use of radio beam forming. Beam forming is a technology that enables (using antennas in the massive MIMO technology) directing the radio signal only towards the receiving device, instead of scattering it in all directions. This technology uses advanced signal processing algorithms to determine the best path for the radio signal to reach the user. It increases transmission efficiency, because it reduces the susceptibility of the signal to disturbances caused e.g. by the phenomenon of radio wave interference.

The use of Multi-RAT technology, i.e. radio multi-access, will enable users, depending on their requirements and on the current network load, to automatically establish connections using the interface(s) that is (are) optimal at a given time (e.g. Wi-Fi, 4G, 3G).

Application of new technological solutions in the 5G radio network involves the need to expand antenna infrastructure and build new antenna installations. They will use new, higher frequency bands while supporting cells of smaller sizes. Thus the power required for transmitting signals using these devices will be correspondingly smaller, also in the case of terminal devices (e.g. smartphones).

IV.3
Applications of 5G

Anna Stolarczyk, Marek Sylwestrzak

Potential applications of the 5G network are mainly due to the ability to handle a very large number of devices of low power consumption (mMTC) and the introduction of the so-called ultra-reliable low latency communication (URLLC – see article IV.2. above). These two features of 5G will enable new mobile network applications and a significant development of existing ones.

Industry 4.0

The fourth-generation industry – also known as Industry 4.0 (its characteristic feature is the use of the Internet and artificial intelligence – previous generations were based on access to computers, electrical appliances, and steam machines) – can benefit enormously from access to 5G technology. Its applications in Industry 4.0 focus on four main areas: robotization (small autonomous robots cooperating with other components of the production process), production process automation, augmented reality (when performing activities such as training, machine maintenance, data visualization and analysis, and design) and logistics management (from orders to distribution, e.g. autonomous handling vehicles).

Pilot actions are already underway in this area.

A Swedish bearing company uses a 5G network to simultaneously customize the product and maximize production efficiency – without compromising flexibility, traceability, sustainability, and safety. The solution is based on the creation of a network of interconnected machines that enable manufacturers to collect, analyze and distribute data in real-time[1].

A certain factory in Tallinn uses augmented reality for troubleshooting, maintenance planning, fault diagnosis, and training, which reduced the cost of failures (additional components, materials, and labor), as well as production downtime. Time savings of up to 50 percent have been achieved[2].

5G is also being used in the mining industry. The new technology improves safety and efficiency in mines, by enabling remote control of machines, smart ventilation, etc. Thanks to the low latency and ultra-fast connectivity, the relevant applications linked to multiple sources of information (audio, video, touch technologies) help people avoid the most dangerous areas. Also, anchor bolts are equipped with a system of special sensors providing information about vibrations to ensure maximum safety when working underground[3].

A Chinese plant w Nanjing uses digital screwdrivers that use mobile telephony based on the "Internet of things" (IoT). In the factory there are about 1,000 precision screwdrivers that require routine calibration and lubrication depending on the time of their use. Previously this was a manual procedure performed periodically and documented in paper logs. The precision tools are equipped with motion sensors working in real-time. The collected data is sent via the cellular IoT network in a private cloud and *back-end* system that enable its processing

1 https://www.ericsson.com/en/cases/2017/skf

2 https://www.ericsson.com/en/news/2018/1/5g-manufacturing---tallinn

3 https://www.ericsson.com/en/cases/2017/boliden

and analysis. With the digital screwdrivers, the factory will be able to replace manual tracking of tool usage data with an automated solution, thus reducing the manual work by 50 percent. As the cost of the device is low, the factory is planning to completely eliminate manual monitoring and maintenance[4].

Self-propelled robots for industrial applications are also built, which can be controlled from anywhere in the world. These "smarter" robots will be able to interact with their surroundings in a human-like manner, identify obstacles, and avoiding them in real time. This requires immediate transmission of an enormous amount of information. For this to be possible, the control function of the robots must be transferred to the cloud in order to use its enormous computing power. 5G Technology provides the necessary lower latency and higher bandwidth compared to other forms of wireless communication.

Vertical integration (vertical market)

5G technology can also be used vertically integrated sectors of the economy. Vertical integration consists in technological combination of separate production, distribution, and marketing phases, or other business processes in a single entity. Vertical integration concerns businesses that are linked with each other within the same production chain.

An increase in the importance of vertical integration will result from the development of Industry 4.0, which will consist in digital integration of all industrial systems and robotization in connection with very little human service inside the entity. The 5G network is to provide the next step in this integration – a complete transformation of the industry. Businesses of the future will jointly produce entire product sets and will work closely together to exchange their technological capabilities so that machines can directly enter into contracts[5].

4 https://www.ericsson.com/en/networks/trending/insights-and-reports/5g-for-manufacturing

5 https://businessinsider.com.pl/firmy/zarzadzanie/przemysl-40-na-fg-time-2018-jaroslaw-tworog/3qjr07k

The 5G network will support a wider portfolio of applications with multiple requirements, from high reliability to very low latency passing through a wide bandwidth and mobility. The above properties will speed up vertical integration in several sectors: automotive, entertainment, e-health, e-industry, and telecommunications.

Engineers are already working on specific applications.

In the automotive sector, these include collection and continuous analysis of vehicle status data and creation of vehicle operation scenarios based on this data which will help car manufacturers to better design them, and also to develop and manage production and sales. Car manufacturers focus in their actions on offering an increasingly high-quality product and on increasing customer satisfaction. More information on faults and usage statistics can help to eliminate failures in the future. Moreover, collection of information on the needs and habits of drivers who use the available services, will enable a more personalized content and services. The 5G network will enable more efficient diagnostics of electronic components whose lifetime is much shorter than that of the whole vehicle.

In transport and logistics, 5G networks can help integrate a company by influencing management of vehicle fleets (financing, maintenance, tracking and diagnostics, speed and fuel level monitoring) and drivers (ensuring occupational health and safety). Vertical integration using a 5G network will enable identification of "bad drivers" and will help to eliminate their dangerous habits, thus affecting fleet safety. Moreover, constant monitoring of vehicle routes will improve the supervision and safety of the goods being transported.

In the clothing industry, the 5G network will enable using the Fashion Tech, i.e. technologies such as electronic tags, smart metering, and progressive lighting and air-conditioning systems that will make it possible to learn potential customer preferences. This is also an investment in smart stores where, with special cameras recording the image in real time and creating heat maps and paths showing the places most frequently visited by shoppers are to enable convenient sale of as many goods as possible and learning about the preferences of potential customers. The data collected would be used to select the best area of the store to display the flagship models of the collection[6]. Use of the 5G technology can help the clothing industry to create and implement new systems to bridge the gap between manufacturers, wholesalers, and retailers.

Smart cities

Smart city services are mostly based on spatial information processed in real-time and affect many spheres of the lives of the residents. A significant proportion of the services based on the 5G technology is located in areas such as smart traffic management (urban communication and road traffic, responding in real time to daily events, e.g. traffic jams), optimization and tracing of energy transmission, monitoring of air pollution and water quality, waste management, infrastructure management in cities, healthcare, and safety.

Examples of specific services planned in the framework of *smart cities* technologies are listed below.

Smart traffic management System will be based on data from roadside control and measuring devices (e.g. sensors, cameras, stop boards), and from urban public transport. It will be possible to adjust the traffic lights in order to optimize the flow of traffic. Information points will provide passengers, in real time, with information on bus and tram arrivals. Information about number of public transport users and about those users who intend to board buses or trams at a given time, collected by integrated operating centers and data platforms, will enable more efficient use of the city's transport fleet. As a result, this should lead to a reduction in the time passengers have to wait for public transport.

Smart traffic lights will monitor the flow of traffic using a network of sensors and cameras. They will be well communicated with buses and will receive information not only about the location of the vehicles on their routes and about how long their delays are, but also about the number of passengers carried at a given time. The system will be able to extend or shorten the duration of the green traffic lights. Optimization of the traffic lights in real time will enable a much more efficient flow of vehicles.

Smart parking will significantly reduce parking time and parking congestion for all drivers. With information on free parking spaces available in real time, drivers will go directly to the spot identified by 5G sensors installed on street lamps or in roadways.

Autonomous vehicles can supplement public transport by solving the problem of the first/last commuter section. Automated vehicles are expected to increase the mobility of seniors and disabled people. Technologies for mutual communication of autonomous vehicles – V2V (Vehicle-to-Vehicle) – and between vehicles and their surroundings, i.e. road signs or signals devices, bus stops, and even the road itself – V2I (Vehicle-to-Infrastructure) – will translate into increased road safety. The number of traffic collisions should be reduced in cities by eliminating human errors, which are currently the most common cause of accidents. Cars will be able to assess the route in advance, avoid congested areas, and planning alternative routes. Furthermore, they will be able to offer passengers alternative transport by verifying the current bus or train times and assessing the fastest way to travel in real time. Due to the ability of autonomous vehicles to travel very close to each other (so-called “convoy driving”), the use of advanced traffic management systems (e.g. dynamic road tolls), and the improved use of infrastructure by designating separate lanes for autonomous vehicles, the capacity of the roads will be significantly increased.

Also, the use of autonomous vehicles should contribute to alleviation of the problem of congestion in cities (autonomous vehicles can be parked closer to each other than at present, when the driver must have enough space to get out of the vehicle and leave the car park) and improvement of fuel economy, while reducing air pollution.

Smart grid will be based on a system of electronic sensors connected by a network that

6 https://www.newsweek.pl/biznes/fashion-tech-nowoczesne-technologie-w-swiecie-mody/0pxr2qh

will be linked to specific software. The system is expected to measure, monitor, control, and optimize energy flows in the grid. Smart grid will allow users to better understand their energy consumption, forecast their needs, and avoid high bills. Energy suppliers, on the other hand, will be able to anticipate increases in energy demand, help in balancing grid load, and avoid waste, which will allow them to improve energy distribution and ultimately lead to lower costs for consumers. In the case of a power failure, a diagnosis will be performed in real-time and the users will possibly be switched to another transformer or device. Energy management is supported by ***smart meters*** which, with the introduction of the 5G technology, will be much more precise than at present (e.g. will enable users to monitor which devices in the house consume the most electricity and at what time of day they bear the most costs), and also by ***remote monitoring of power facilities*** (such as wind farms and photovoltaic power stations). Both smart meters and remote energy monitoring are not new functionalities but, with the introduction of 5G services, the increased data transmission rate and a much lower latency will translate into more detailed information collected.

With **smart lighting systems**, the lighting intensity will be adjusted according to the traffic intensity and the time of day. Data from motion and weather sensors installed in street lamps will enable automatic control of lighting based on weather conditions, street use, and availability of natural light, which will reduce energy consumption, extend lamp life, and reduce replacement costs. Bulbs will also be equipped with individual sensors, so that light levels will automatically change in response to cloudy weather or low traffic levels. Information from the sensors will be sent to the control system and, after processing, will be available to residents. In the event of a power failure, the smart technology will enable precise diagnostics in real time to identify the specific transformer, which will speed up repairs and shorten downtime. Car park lighting will work similarly to the street lighting system, i.e. it will be dimmed when no traffic is registered and when a car enters the car park and is detected, the relevant sectors can be illuminated.

Smart buildings will use different systems to ensure safety and to maintain resources and general health in the surroundings. Smart buildings include: ***security systems*** (remote monitoring, bio- metrics, wireless alarms), ***smart heating and ven- tilation*** (monitoring of various parameters, such as temperature, pressure, vibrations, humidity in buildings), ***smart water management*** (mobile applications will allow consumers to control the use of water resources in of their homes).

In the area of **security**, the new solutions may include e.g. ***Closed Circuit TeleVision*** (CCTV) which transmit several HD and 360º video streams in real-time. The monitoring may cover public places or critical infrastructure. It can be combined with facial, iris, or fingerprint recognition systems that enable effective identification of missing persons or persons suspected of committing crimes. The system should lead to increased security, as it will be able to automatically send information on registered offenses to the relevant services. The ***automatic threat detection system***, allowing detection of suspicious objects, anomalies, and disturbances in public places, including weather events posing a threat to the public, will serve the same purpose.

E-health

The 5G technology will enable a revolution in healthcare and medical services. Let us look at the most important planned services and technologies.

Telecare and telemedicine, i.e. remote consultation of patients with physicians via mobile devices. Implementation of the 5G technology will enable a wide spread of high-quality videoconference services, enabling patients to consult on smartphones, tablets, etc. This technology will evolve using accelerometers integrated in most smartphones. It will turn smartphones into devices that will alert the competent healthcare service (e.g. that a patient has fallen) or that will send information about the health condition of a patient to the doctor to allow him/her to make a proper diagnosis. Thanks to the video calls, it will be possible not only to receive medical advice but also to participate in rehabilitation.

Monitoring of patient health and activity (including e.g. use of medicines) will be carried out by means of mobile devices (smartwatches, smart glasses, etc.). These devices, belonging to the IoMT ("Internet of Medical Things") group, will support fully predictive analysis, significantly shorten the time needed to detect health problems, and significantly increase the accuracy of the doctor's diagnosis. Thanks to the application in which cameras and sensors will monitor daily activities, doctors will know what stage of therapy their patients are at, which will help to choose the right treatment.

Smart medicines will reduce treatment costs and help avoid side effects. The objective of collection of personal health data in real time will be to ensure a personalized pharmaceutical approach. The system will be able, e.g., to measure the level of antibodies in the blood and, on this basis, decide whether an extra dose of a medicine is needed.

Telesurgery, i.e. procedures carried out using high quality 360º cameras and surgical robots, can also be implemented. Telesurgery also includes the use of tactile devices, such as gloves that allow the surgeon to move remotely and "feel" the patient being operated from another location.

Smart ambulance will be based on the communication in real-time between the hospital and the ambulance (from the site of a medical event) to make data available and to conduct consultations. The 5G technology will also detect when a dependent person leaves home and is in danger of getting lost or that something may happen to him or her if the person does not move for a long time.

Mobile robots will support, among others, elderly or disabled persons. Singapore is already testing a solution which, by using motion sensors in homes, allows working Singaporeans to monitor whether their relatives remaining at home are safe. If there is no movement for a long time, the system immediately informs the caregiver's smartphone, who can react immediately, contact his or her relative and find out if everything is all right. This allows caregivers to work and avoid having to choose between their family responsibilities and their careers.

Environmental protection

Potential applications of the 5G technology for environmental protection are largely the direct result of the development of IoT and smart cities services, which are based on all kinds of wireless sensors. In its broadest sense, a 5G network can facilitate a cleaner, greener, and a more environmentally friendly future, increasing the efficiency of many processes.

Examples of applications, which were not mentioned earlier, that will be developed together with 5G and more efficient operation of IoT sensors, are monitoring of vibrations and material conditions in buildings, bridges, and monuments; noise level monitoring in cities and on their outskirts in real time; measurement of the energy emitted by mobile telephony stations and Wi-Fi routers; more efficient waste management and recycling – detection of waste levels in bins, development of tracking and recycling services for products of higher value or most harmful to the environment (electronic equipment, batteries, furniture, etc.); monitoring of forests and protected areas for fires; monitoring of the condition of air, emitted pollutants, water level, and precipitation level; better prediction of earthquakes; more efficient control of dangerous spills; and monitoring of growth conditions of endangered plant and animals species to ensure their survival and health[7].

More efficient monitoring – in real-time – and more precise sensors will translate into a faster response to emergencies and disasters, which is often crucial for rescuing people at risk and the natural environment.

7 Libelium, 50 Sensor Applications for a Smarter World, http://www.libelium.com/resources/top_50_iot_sensor_applications_ranking/

Agriculture

Agriculture is a branch of the economy exposed to high risk and low profits; therefore, increasing the precision of operation and the productivity in this sector is crucial. The 5G technology provides new possibilities in monitoring, tracking, and automation in agriculture. Thanks to the IoT, information on humidity, fertilization, and soil nutrients, as well as current weather forecast reports will be provided for better crop management and breeding. This will also enable monitoring of the maturity of farm animals and their feeding parameters, which should help farmers in precise determination when the animals can be sold. The 5G Technology will ensure tracking of the vast number of environmental factors that affect agriculture, thus optimizing operations, even in areas where broadband is not provided[8]. So-called smart agriculture, based on, among other things, automation and robotics, using artificial intelligence at every stage of production, as well as precise measurements and actions based on collected data, is an absolutely necessary technological innovation to help feed an ever-growing population struggling with climate change problems. Moreover, 5G can support crop monitoring with drones equipped with video and infrared cameras, which would enable faster detection of sick, injured, or missing animals and monitoring of plants without the need for the farmer to leave his house[9]. The 5G network should provide precision equipment for agricultural machinery in order to optimize and improve traditional agricultural operations, and to provide feedback on environmental conditions or equipment in use and its performance, maintenance, and repair parts needed.

The 5G technology can provide farmers with a wealth of real-time data on water and energy consumption, livestock movements, condition of machinery, and market prices. As a result, 5G can help regional companies to compete on a level playing field both nationally and globally, driving investment and encouraging further deployment of new technologies.

Acilities for disabled persons

5G are not only autonomous cars, *smart cities*, development of education, and improved safety, but also new opportunities for elderly and disabled persons, especially in the context of prevention of their exclusion from the society.

The 5G network will support services for people with all types of disabilities: motor, visual, hearing, and speech impairments, as well as for people with chronic diseases that require continuous monitoring of vital functions.

Application of 5G in autonomous vehicles will allow them to be driven automatically, thus increasing the mobility of people with disabilities and their safety in road traffic, through continuous monitoring and analysis of the situation on the road[10]. On the other hand, the use of sensors in vehicles and low latency in data transmission using 5G can be used to design cars for blind people[11].

Location and navigation services will facilitate movement and reaching their destination in urban areas to blind and visually impaired persons. Current solutions that make it easier for blind persons to move in shops or in built-up areas are based on the help of another person[12]. The 5G technology, on the other hand, can be used to design smart headphones that will provide highly precise information in real time regarding current location, navigation to a designated destination, and obstacles. Such a solution is also supposed to offer a whole range of additional functions, such as face recognition, identification of the situation, and recognition and categorization of objects. All this can help blind people to overcome everyday challenges[13]. Furthermore, thanks to the faster data transmission and, thus, image transition, death persons using

8 http://www.carritech.com/news/5g-use-cases-sensor-networks-farming-agriculture/

9 https://disruptive.asia/5g-smart-farming-green-revolution/

10 https://5gmf.jp/wp/wp-content/uploads/2016/09/5GMF_WP101_12_Network_Tech_for_5G.pdf

11 https://about.att.com/innovationblog/blindcaptain

12 https://about.att.com/innovationblog/aira_wearables

13 https://www.huawei.com/minisite/giv/en/era.html

The 5G network will support services for people with all types of disabilities: motor, visual, hearing, and speech impairments, as well as for people with chronic diseases that require continuous monitoring of vital functions.

the sign language will be able to participate in video conferences[14].

A combination of the 5G technology with the "Internet of things" can improve the standard of healthcare for people with disabilities and, in combination with smart buildings, can improve the living conditions in homes[15]. With the installation of sensors and the 5G technology, persons with chronic diseases and various dysfunctions will be able to control home appliances, improve safety, transfer health data to medical professionals, and develop their careers through remote working. This will also enable building emergency detection schemes and responding quickly to emergencies.

Education and games

Use of 5G in e-learning and games focuses on several areas. The first is remote e-learning, which replaces traditional teaching methods by using video streaming tools of an unprecedented quality and speed. Another is augmented education, which enables learning new content through the use of so-called "augmented reality" which, due to the transmission of large amounts of data, requires a fast network. *Augmented reality* is a system that connects the real world with computer-generated content. Typically, this is done using the image from a camera, completed with images, sound, and in certain applications also tactile and olfactory stimuli, generated in real time. With augmented reality, it is possible to provide the user with additional information superimposed on the actual surrounding space. In the entertainment sector, there are games that, by using augmented reality, give a new dimension to existing games with a large number of players and also enable playing outdoor.

In the area of education, development of 5G enables planning many modern services. 5G will make possible e.g. interactive video conferences and remote classes – on a mobile phone. Travel abroad will be facilitated by guides with geolocation, installed on mobile devices, showing plans of buildings, additional information on buildings or some other objects, information on tourist attractions, and personalized suggestions concerning hotels or restaurants, as well as by interactive translation applications working in real time, based on information from cameras or recorded audio.

The ability to identify a recorded image or sound sample by automatically searching the Internet will also increase – as a result, a known image or music piece can be identified. Biology classes can be enriched by identification of an animal that makes a particular sound (e.g., twitting of a specific bird species). This way of presenting knowledge and of interactions with teaching materials can be interesting and can speed up children's learning, compared to learning from an ordinary book. It will allows enable individual adaptation of the scope, form, manner, and speed of information transmitted in the learning process, according to the abilities, predispositions, and needs of the students.

There will be geolocation games with augmented reality that will enable (using a smartphone) determination of the current location of the player and then displaying information related to the real world. Such a game reacts to a player's movement or orientation in a specific direction, or location near a building. The game can also send the player's location data to other participants, allowing additional interactions. Another type of

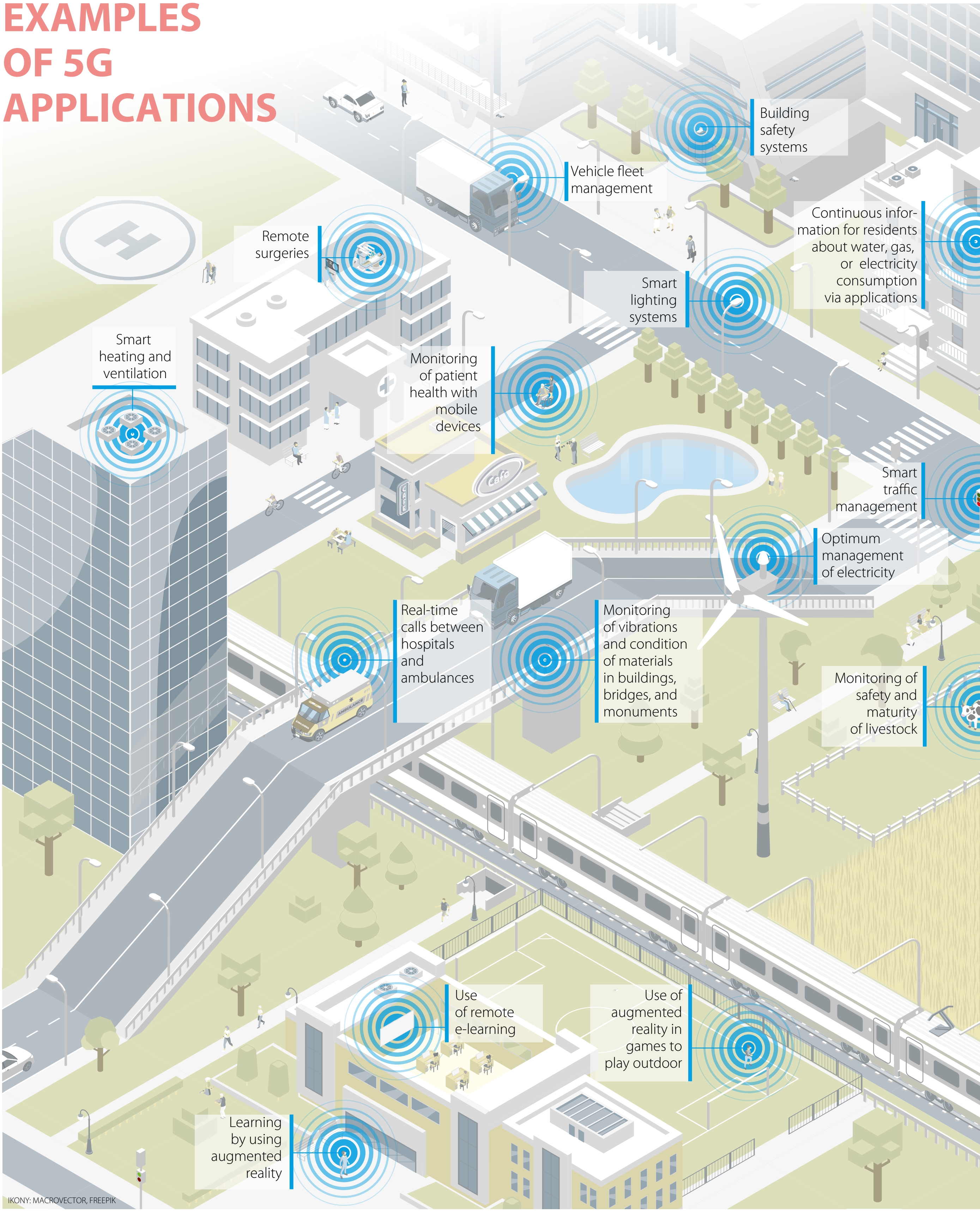
14 https://www.ctia.org/news/5g-will-spur-new-opportunities-for-americans-with-disabilities

15 https://www.rcrwireless.com/20150602/internet-of-things/iot-enabling-the-elderly-and-disabled

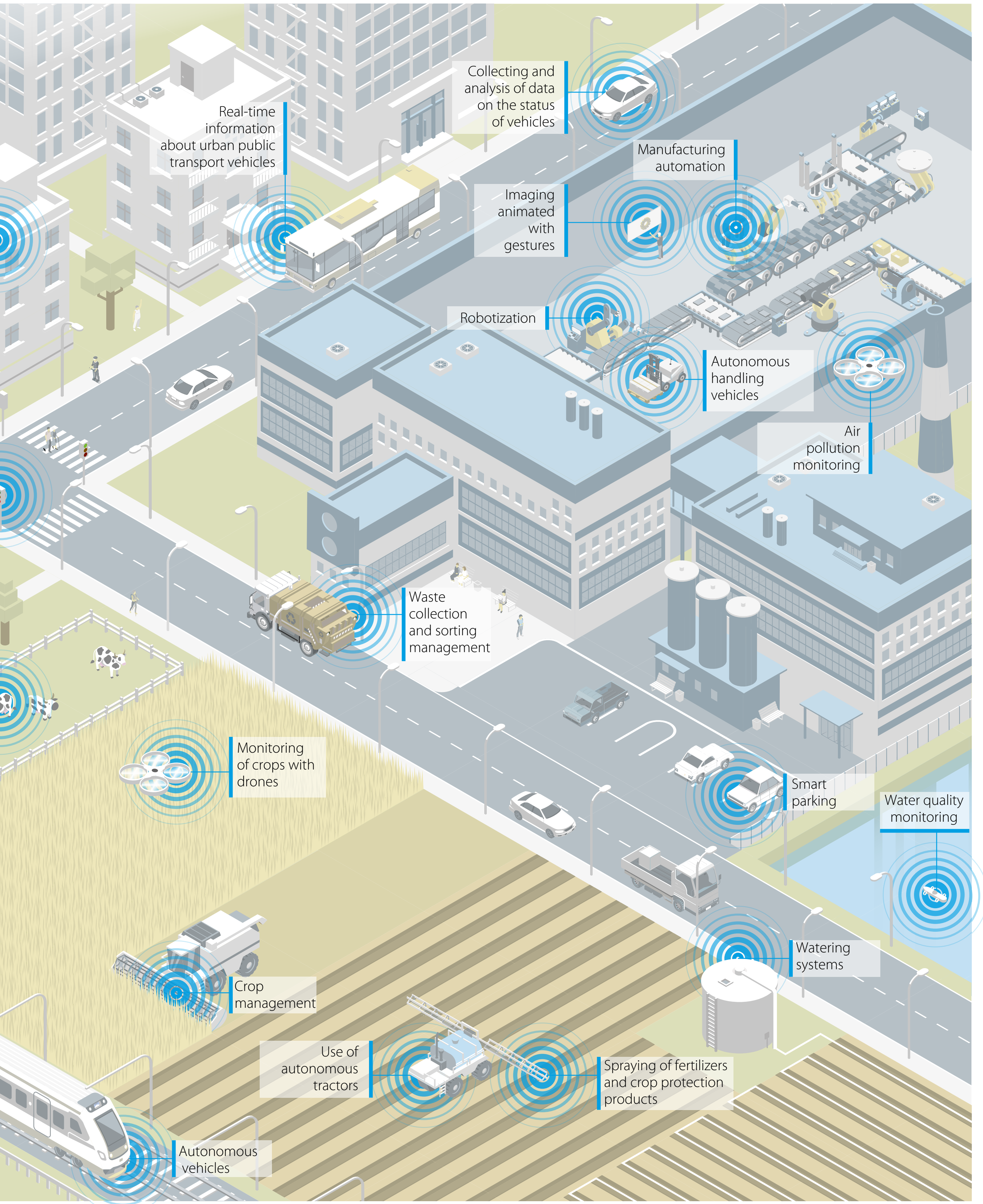
entertainment and competition will be provided by remote action games or remote sport applications, e.g. ones that enable player to race on foot or by bicycle with person present in another city (by comparing their results with other players racing at the same time or by virtualizing other players).

Of course, these are not all possible applications of the 5G network, but rather only those we can already predict. Human creativity knows no bounds, however, and we can expect that inno- vators, visionaries, and inventors will surprise us many times in the future. We can also be sure that, over the next decade, our lives – in the smart cities, with access to a number of new services, including e-health - will become more convenient and safer, and the benefits resulting from the technological changes will affect increasingly wider groups, in- cluding most disadvantaged ones.

EXAMPLES OF 5G APPLICATIONS



IKONY: MACROVECTOR, FREEPIK


Real-time information about urban public transport vehicles
Collecting and analysis of data on the status of vehicles
Manufacturing automation
Imaging animated with gestures
Robotization
Autonomous handling vehicles
Air pollution monitoring
Waste collection and sorting management
Monitoring of crops with drones
Smart parking
Water quality monitoring
Watering systems
Crop management
Use of autonomous tractors
Spraying of fertilizers and crop protection products
Autonomous vehicles

IV.4

What are the benefits of 5G?

Barbara Bartoszewska , Magdalena Olender-Skorek

The development of 5G helps to achieve the full range of benefits for both the society (citizens and businesses) and the whole economy.

For citizens

From the point of view of the individual citizen, the greatest benefit will be the availability of newly created services, better tailored to the needs of the individual user, personalized, and more advanced, and above all provided faster and more efficiently. Citizens (in real time!) will use interactive e-services: will apply advanced e-health diagnostic methods, benefit from the knowledge and capabilities of e-health, make use of *smart city*, and even more efficiently deal with official matters. This will save time and money that citizens would have to spend on offline services.

There are also clear benefits to citizens in the area of entertainment, e.g. through the possibility to participate in mass cultural events using high-quality digital media (4K and 8K data transmission on smartphones will be possible). 5G will be essential for the development of new technologies supporting the future digital society, which will comprise a large proportion of commercial transactions.

Thanks to 5G, it will be possible to increase the use of drones in rescue operations (e.g. during disasters), which require high quality HD cameras connected to mobile broadband Internet, low latency in transmission, and high availability. This will enable reliable and safe piloting of drones, so that rescuers can reach any location in a safe way without endangering the lives of people. 5G will also improve the safety in everyday life, by revolutionizing the ways smart homes are implemented and maintained. It is assumed that 5G will help to solve the basic problems of users, e.g. difficulties with configuration of devices, their unreliability, and high latency. Use of cellular communication via the 5G technology, instead of home WLAN networks and firewalls, will also improve the performance of users and will better protect their devices.

The 5G technology will also bring about a change in the structure of employment. There will be new professions and many of the existing ones will be supported by technologies or will be completely replaced by machines. For citizens, this change will be beneficial as there is already a shortage of low-skilled workers in the market for routine, repetitive jobs.

With 5G, it will be easier for households to manage their expenses. It is estimated that the energy consumption itself will be reduced by 20%[1], which (looking at today's structure of spending of an average household[2]) translates to about PLN 45 of savings per month. Also, food purchases should become more reasonable (less food waste due to the so-called “smart shelves” in refrigerators). Assuming that households will throw away a half of

1 “The value of 5G for cities and communities”, *Juniper Research*, 02, http://www.mobileuk.org/cms-assets/O2%20Smart%20Cities.pdf.

2 CSO, “Household budgets in 2017,” http://stat.gov.pl/obszary-tematyczne/warunki-zycia/dochody-wydatki-i-warunki-zycia-ludnosci/budzety-gospodarstw-domowych-w-2017-r-,9,12.html.

what they currently do, the associated monthly savings can reach PLN 100. Autonomous electric cars will save fuel worth on average PLN 200-300 per month (this is the most common amount of expenditure on petrol per household[3]).

For businesses

Use of 5G by businesses will allow them to process and store larger volumes of data without expanding their existing hardware resources. Furthermore, the elimination of data transmission latency will improve remote access to devices in automated businesses. This will ensure that there will be no need to maintain low-productivity jobs, for which employees are currently very difficult to find. In addition, by increasing (even 100 times) the Internet speed, companies will be able to communicate in real time with their contractors and branches, present data, and hold video conferences even in 4K or 8K resolution (also via smartphones). This will reduce the time required and the costs generated by business trips (a reduction by at least 75% is estimated). At the same time, sensor systems will enable businesses to reduce their electricity consumption.

The beneficiaries of the emergence of 5G will include telecommunications companies themselves, as they will be able to use their infrastructure more efficiently to provide better quality services. According to the estimates of the GSMA[4], as a result of the introduction of 5G, the index reflecting the value of telecommunication companies (the so-called Cumulative Annual Growth Rate, CAGR) will increase on average by 2.5% to 5% annually (the value of telecommunication companies will start growing faster).

3 Ibid.

4 "The 5G era: Age of boundless connectivity and intelligent automation", GSMA, 2017.

Benefits for the economy

The most important benefit of 5G for the economy is GDP growth, which is estimated at about 7% worldwide. A comparison of this figure to the current GDP of Poland (nearly PLN 2 trillion in 2017), it can be calculated that the GDP should grow by PLN 138.8 billion. A big part of it, as much as 48%, will result from the revenues generated by creation of new services[5].

5G will have a positive impact on economic growth through capital expenditures, increase of production capacity, and improvement of the quality of the workforce. More efficient use of resources will lead to increased prosperity of the society. The sooner the value added to GDP generated with 5G appears, the sooner Poland will enter the growth path. The authors of the document commissioned by the European Commission[6] estimated that in the industry itself, the 5G technology will increase added value by 1% (excluding the car industry, which was subject to a separate analysis). The added value of the industry in Poland, according to CSO data, amounted to almost PLN 336 billion in 2016. A one percentage point increase in productivity will thus translate into benefits on the national scale equal to PLN 3.3 billion per year.

The development of individual industries will translate into additional savings, which are estimated at up to twenty percent a year. The decrease in transport costs alone will make it possible to save approx. 2% of the current costs which, compared to the data from the CSO (on the costs of transport activity in Poland), translates into PLN 1.8 billion. The development of e-health, on the other hand, will result in annual savings of the state on the level of PLN 150 million (0.13-0.2% of current health expenditure).

As the 5G technology affects almost all areas of socio-economic life, it will also indirectly help **improve the international competitiveness** of the economy.

5 "The 5G business potential", Arthur D. Little and Ericsson, 2017.

6 "Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe," Report commissioned by the European Commission, 2016.

Glossary

ALARA (*As Low As Reasonably Achievable*) – a safety rule applicable to exposure to of ionizing radiation

antenna – a device transmitting and receiving an electromagnetic wave that contains the desired signal

radio link antenna – in mobile telephony networks, an antenna for communication with other base stations or with the base station controller

sector antenna – in mobile telephony networks, an antenna for communication between the base station and user terminals, which covers a specific sector, usually 120 degrees; there are multiple sector antennas on a single base station, covering all directions, i.e. 360 degrees

frequency – one of the parameters of the electromagnetic wave, describing how often (how many times in a given unit of time) the electromagnetic field returns to the same state at a given point; as an illustration: how many times per second a wave "peak" occurs in a given point; the unit of frequency is hertz [Hz]

wavelength – the distance between any two wave crests, e.g. in the case of an electromagnetic wave, but also an acoustic or mechanical wave; its unit is a meter [m]

dosimeter – a device for measuring the doses of ionizing radiation and radioactive activity of substances

exposimeter – a device for recording exposure to an electromagnetic field; this allows individual measurement in any environment, e.g. in the place of residence

electrosensitivity, see electromagnetic hypersensitivity

electromagnetic wave – a form of the electromagnetic field in which is a regular, interlinked change of the parameters of the electric field and the magnetic field takes place; formally, the change of the vectors of the electric field and of the magnetic field have the sine form; as an illustration, this is a phenomenon quite similar to the waving of water surface; the electromagnetic wave is described by frequency and wavelength

photon – a single particle of electromagnetic radiation

power density – one of measures of the electromagnetic field; its unit is watt per square meter [W/m^2]

penetration depth – a measure of interference of electromagnetic radiation with matter; it is the depth, calculated from the surface of a given body, at which 86.5% of the initial power density is absorbed; its unit is meter [m]

cell – the area of single base station

signal modulation – superimposition of useful information on the signal (the "raw" signal before the modulation, which does not yet contain this information, is referred to as "carrier signal"); modulation makes it possible to transmit information e.g. by means of electromagnetic waves; two examples of modulation are amplitude modulation (AM) – information is contained in changes of the carrier signal amplitude – and frequency modulation (FM) – information is contained in changes of the carrier signal frequency

electromagnetic hypersensitivity (EHS) – a problem reported by a certain group of people (about 3% of the population according to some studies); an exceptionally strong tendency to experience some negative symptoms (fatigue, weakness, tinnitus, insomnia, etc.) due to the presence of electromagnetic field; the causes of the EHS are not known, although according to some research it may have a psychological nature and be partially or fully explainable by the nocebo effect

electromagnetic field strength – one of the measures of electromagnetic field; usually the strength of the electric component (E), in volts per meter [V/m], and the strength of the magnetic component (H), in amps per meter [A/m], are reported separately

measurement uncertainty – a parameter always associated with the measurement result, characterized by the spread of values resulting from the fact that each measurement is made with finite accuracy

nocebo – a psychological effect consisting in the occurrence of undesirable symptoms exclusively due to a negative attitude (e.g. to some therapy, some physical phenomenon, etc.); the opposite of the placebo effect, which consists in the occurrence of positive medical effects due to a positive mental attitude, even in the absence of any physical therapeutic factor

near field – the electromagnetic field observed relatively close to the antenna; in this area, it depends on the current values of current and voltage in the antenna, and the relationship between the electric field and the magnetic field can be very complicated

far field – the electromagnetic field observed relatively far from the antenna; in this area, the momentary changes of current and voltage in the antenna are averaged, and the field is relatively "smooth;" field measurements should be performed in the far field

electromagnetic field (EMF) – a unified way of describing the electric field and the magnetic field, proposed in the 19th century by J. C. Maxwell

electric field – a state of space associated with presence of electric charges; it is quantified by the electric field strength E

magnetic field – a state of space induced by moving electric charges or by certain materials referred to as permanent magnets; it is described quantitatively by the magnetic field strength H

selective measurement – measurement enabling the assessment of the level of electromagnetic field in a specific frequency range, allowing the identification of the frequencies of the components of the measured electromagnetic field

broadband measurement – measurement which results in the total value of the electromagnetic field in the measuring range of the probe, with no possibility to identify the component frequencies; without additional measurements and calculations, it cannot constitute grounds for assessment of the maximum level of this field

electromagnetic radiation – in the most general sense, this term refers to all forms of electromagnetic field variable in time; in practice, EM radiation is usually discussed with reference to the high-frequency form of the field, e.g. X radiation, but not radio-frequency radiation

ionizing radiation – radiation that is able to cause ionization, i.e. can turn an atom or an electrically neutral particle into an ion, i.e. a charged particle; the simplest way of ionization is to break out an electron from an atom/particle; only radiation of an appropriately high frequency (sufficiently high energy of individual photons), e.g. X or ultraviolet radiation, is ionizing

non-ionizing radiation – radiation whose energy is not sufficient to cause ionization; as a result, the interaction of this type of radiation with matter is not chemical, but thermal at most: it does not cause the formation or destruction of chemical bonds but can cause the matter, including the human body, to heat up; radio waves and microwaves are non-ionizing

thermal radiation – electromagnetic radiation emitted by the surface of every physical body solely because of its temperature; in the case of bodies at room temperature, it falls into the infrared range and is invisible to the naked eye; sunlight, which is visible to the naked eye, is the thermal radiation of the Sun, whose surface has the temperature of around 5,500°C

propagation – a technical term describing the movement ("travel") of waves, e.g. electromagnetic, mechanical, or acoustic waves, in space; such waves may be scattered, refracted, or reflected; the study of the propagation of electromagnetic waves is of great importance to the design of telecommunications networks

backbone network – a set of components of a cellular network that connect the base stations to each other; it includes the transmission system, including radio links, optical fibers, packet data transmission equipment, etc.

base station – a transmitter/receiver radio device installed on a support structure (a mast or a tower) and equipped with antennas, which is the basic unit of the mobile telephony system; all terminals ("receivers") in a given area, referred to as cell, connect with a specific base station; antennas contained in the base station are the source of the signal received, among others, by all mobile phones currently present in that cell

specific absorption rate (SAR) – a measure of the rate of absorption of electromagnetic radiation converted in tissues of the human body into heat; in other words, the power absorbed by a unit of body weight; its unit is watt per kilogram [W/kg]

terminal – a terminal transmitter and receiver device; in the case of communication in a mobile telephony network, typical terminals are mobile phones and modems

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