Basic knowledge of radiofrequencies and wireless communications

1. What are electromagnetic waves?

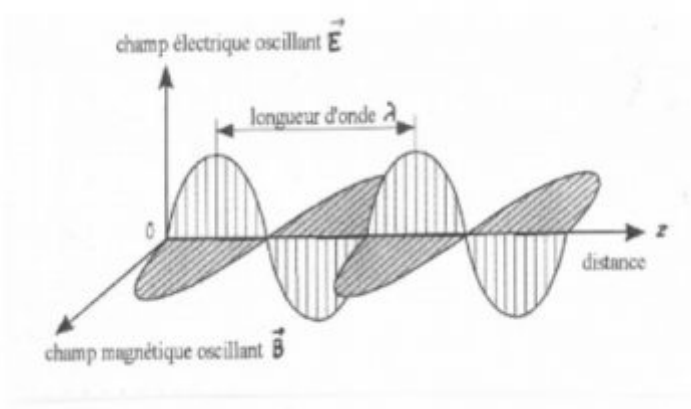

Figure 1. Schematic representation of an electromagnetic wave (wave model). [Source: https://www.encyclopedie-environnement.org/en/air-en/colours-sky/]

Electromagnetic waves result from the combination of an electric wave and a magnetic wave that propagate in a vacuum at the speed of light (Read **The colours of the sky**). It is also called **radiation**. The **frequency** (in Hertz, Hz) corresponds to the number of oscillations per second, it is inversely proportional to the **wavelength λ** (in meters) which represents the distance between two points of oscillation (Figure 1).

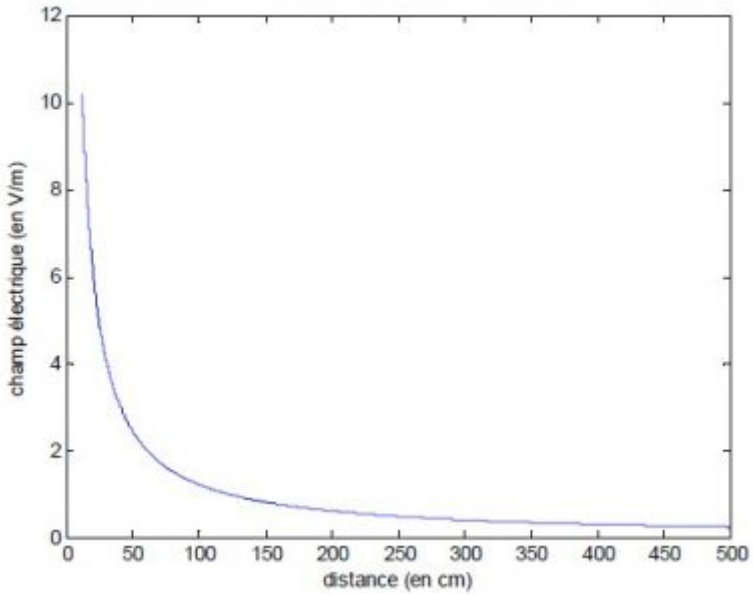

Figure 2. Electric field value (V/m) as a function of distance from a 50 mW transmitter. [Source: ANSES report 2013]

Each wave is associated with a particle (photon) whose own energy depends on the frequency. The range of radiation extends from zero frequency corresponding to static electric and magnetic fields, to infinity (cosmic radiation) (Figure 2).

2. Radio frequencies and wireless communications

Radio frequencies are **electromagnetic waves, also known as radio waves or frequencies,** whose frequencies are by convention lower than **3000 GHz** according to the International Telecommunication Union [1]. This range includes frequencies that are also known as radio waves, high frequencies, microwaves or even microwaves. The frequency bands are officially allocated for the various applications [2]. The so-called millimetre waves (due to their wavelength in the order of a millimetre) are located in the upper part of the radio frequency range. Infrared and visible radiation are above 300 GHz.

3. Wave propagation in space

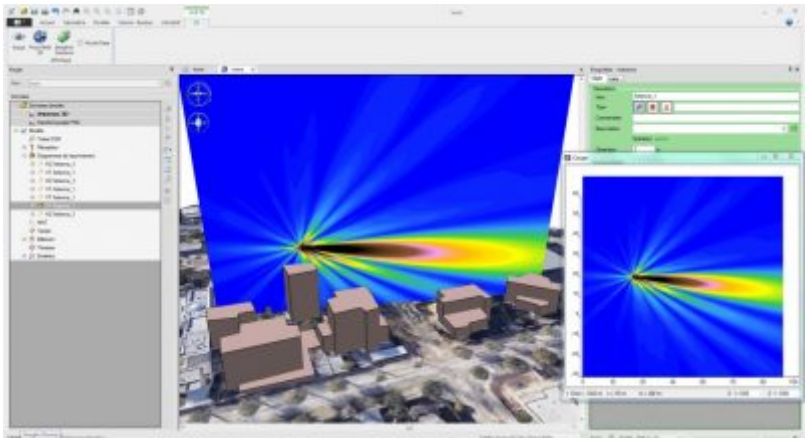

Figure 3. Numerical simulation experiment to produce an image of the beam spread from a relay antenna, color scale to indicate electromagnetic field levels. [Source: image obtained with the MithraREM software, provided by CSTB]

In the absence of obstacles, the electromagnetic waves propagate in space from the radiation source, occupying an increasingly large space. The power of a transmitter is expressed in **watts**. The intensity of the electric field at a given location decreases rapidly with distance from the source (Figure 2). We can visualize this easily in the case of visible radiation, since our eye is able to capture light, for example from a flashlight. This phenomenon is similar from a telephone relay antenna. Exposure is lowest under the transmitter, the so-called **umbrella effect** (Figure 3).

4. Wireless communications and mobile telephony

More than a century ago, radio frequencies were used for **radio**, followed by **television** in the 1960s. In addition, many wireless communication systems have developed (Wi-Fi, Bluetooth, connected objects, etc.), including the fixed wireless home phone (DECT). These technologies, especially **mobile telephony**, have grown rapidly over the past 30 years. Like most technologies, they have been constantly evolving since their invention. The wireline telephone is gradually disappearing and mobile telephony is now part of public services; coverage of the territory is an obligation for operators [3].

4.1. Mobile telephony: how does it work?

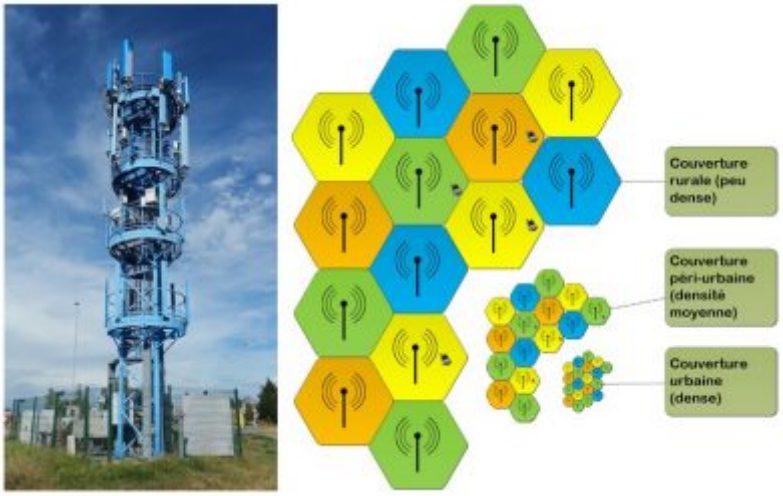

Figure 4. Base station and principle of a mobile phone network. [Source : photo and diagram by A. Perrin]

The mobile phone is a **receiver**, like a radio, but also a **transmitter** of waves to send information back. The operating principle of mobile telephony is based on the division of the territory into "honeycomb" cells. In each cell, a fixed base station (a site with one or more antennas and associated equipment) transmits to the users' mobile phones and receives signals from the phones active in its cell (Figure 4). The mas can also carry other transmitters or sensors for radio, meter reading, lighting management..

In France, several tens of thousands of base stations, commonly called relay antennas, are operated by four separate networks. There are now about **seven billion subscriptions** in the world [4]. Some countries have never had wireline telephony before because of the heavy infrastructure required.

4.2. Evolution of mobile telephony over time: 1, 2, 3, 4 and 5G

Figure 5. Overview of frequency bands identified for 5G. [Source: © ANFR]

First generation (1G) wireless phones date back to the 1980s, but mobile telephony became popular in the 1990s with the much more manageable second generation (2G, GSM system) devices, which also allowed for the sending of written messages. In the 2000s, networks and signal encoding were optimized to transfer more data (internet, images, videos) and smartphones appeared (3G, 4G, UMTS systems, LTE) [5]. **Now 5G is developing in the world** and will probably gradually replace the previous networks [6]. This new technology is similar to 4G, but allows to reach higher speeds with shorter latency times, i.e. more capacity and reactivity, especially thanks to new active antennas (also called massive-MiMo or smart). They will no longer transmit continuously in all directions of the beam but towards the devices that connect. However, 5G can also work with antennas from previous generations [7]. The applications envisaged go beyond mobile telephony and 5G is announced as bringing innovations in a multitude of public and especially industrial sectors [8]. The frequencies already allocated to telephony may be used, as well as two new frequency bands: 3.5 GHz (3.4-3.8 GHz) and 26 GHz (24.2-27.5 GHz, known as millimetre waves). Higher frequencies are also possible (Figure 6). For the time being, the deployment of the 3.5 GHz band has been launched.

In France, the frequency ranges used (or to be used) according to the mobile telephony generation are as follows

2G: 900 MHz and 1.8 GHz

3G: 900 MHz and 2.1 GHz

4G: 700 and 800 MHz, 1.8; 2.1 and 2.6 GHz

5G: 700 MHz to 2.6 GHz, around 3.5 GHz, and in the future, around 26 GHz.

It should be noted that WiFi has long been operating at 2.4 GHz and 5 GHz, and probably soon at 6 GHz [9].

5. Some orders of magnitude

The power of wireless communication systems ranges from milliwatts to a few watts for proximity devices. The most powerful transmitters are far from the body. Telephone relay antennas have a power of about 1 to 50 watts depending on the area covered. Television or radio transmitters can reach several thousand watts and are located high up, generating an electric field of the order of V/m on the ground. The power of radio equipment intended for general public use rarely exceeds 1 or 2 watts. For example, 2.4 GHz WiFi routers emit a maximum of 100 mW, and the order of magnitude is similar for DECT (fixed wireless) phones.

6. How to measure the level of exposure?

In the radio frequency range, the **level of exposure** at a given location can be obtained by measuring the electric field or the magnetic field, as both vary in the same proportions. The level of exposure is usually expressed in terms of **electric field (volts per metre, V/m)** or **power density (watts per square metre, W/m2)**. These two quantities are related to each other and can be obtained using field strength meters adapted to the frequency range under consideration, following a rigorous protocol [10]. For technical reasons, these devices are only able to measure the electric field correctly at a certain distance from the source. They

cannot be used in the vicinity of a mobile phone or other transmitting device located close to the body, although they still display a value, which is false! It is then necessary to use more sophisticated tools to measure the **specific absorption rate (SAR)** which quantifies the amount of energy absorbed per kilogram and is expressed in W/kg. These measurements are carried out in specialized laboratories. They provide the maximum level of exposure to people that can be reached when the device is operating at full power.

Notes and references

Cover image. [Source: image obtained with the MithraREM software, provided by CSTB]

[1] International Communications Union, Radio Regulations, 2012. On itu.int

[2] ANFR, Tableau national de répartition des bandes de fréquences

[3] Mobile operators' obligations towards the State and users of their services

[4] International Telecommunication Union, World Telecommunication/ICT Development Report and Database.

[5] GSM: Global System for Mobile Communications; UMTS, Universal Mobile Telecommunications System; LTE, Long Term Evolution (mobile telephone standards).

[6] The deployment of 5G, on anfr.fr.

[7] ARCEP, Dossier 5G, Technical aspects of 5G: intertwining 4G and 5G, online resource of 10/11/2020. On arcep.fr

[8] Information on the deployment of 5G in France on the ARCEP website (arcep.fr)

[9] ANFR, " A new band for Wifi at 6 GHz?", Anfr news, 2 June 2020. On anfr.fr.

[10] ANFR, Protocole de mesure. Version 4.1, October 2019.
