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Impact of the electromagnetic waves on the human health and environment: study and analysis

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Dedication

We give thanks to God for the completion of this modest work. We dedicate this project to our fathers and mothers, our brothers and sisters, and our teachers, ***Mekimah Boualem*** *and* ***Boulesbaa Mohammed****, whose support and guidance have been invaluable. We thank the member of jury for accepting the examination of this work. Our special thanks go to Amira Hamidi for her effort to complete this work.*

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.

Abstract

This study examines the effect of electromagnetic waves on human health and environment. It focuses on how varying frequencies (900 MHz, 1800 MHz and 2400 MHz) impact tissue absorption and health risks, using Finite-Difference Time-Domain (FDTD) method. Findings reveal significant differences in tissue absorption, emphasizing the need for careful frequency and power level regulation. The research also highlights environmental impacts, such as adverse effects on wildlife like honeybees and birds. Overall, it provides crucial data for developing safer communication technologies and informing regulatory guidelines. The results show that the specific absorption rate (SAR) is high near to radiating sources. Also, at high frequencies the field attenuation is high. The best way for avoiding the effect of electromagnetic waves is to staying away from any radiating sources, such as cell phones, BTS, relays, antenna and so on.

Key words: Electromagnetic waves, SAR, FDTD method, human tissues, Attenuation.

Résumé

Cette étude porte sur les effets des ondes électromagnétiques émanant des technologies de communications sans fil sur la santé humaine et l'environnement. Il se concentre sur la manière dont différentes fréquences (1 800 MHz et 2 400 MHz) affectent l'absorption tissulaire et les risques pour la santé, à l'aide de simulations utilisant la méthode du domaine temporel des différences finies et MATLAB. Les résultats révèlent des variations significatives dans l'absorption tissulaire, soulignant la nécessité d'une régulation précise de la fréquence et du niveau d'énergie. La recherche met également en évidence les impacts environnementaux, tels que les effets néfastes sur la faune comme les abeilles.

Mots clés : ondes électromagnétiques, taux d'absorption spécifique des ondes SAR, méthode du temps de dispersion déterminant (FDTD), tissus humains, équation de Ferris.

الملخص

تتناول هذه الدراسة تأثيرات الموجات الكهرومغناطيسية الصادرة عن تقنيات الاتصالات اللاسلكية على صحة الإنسان والبيئة. وهو يركز على كيفية تأثير الترددات المختلفة (1800 ميجا هرتز و2400 ميجا هرتز) على امتصاص الأنسجة والمخاطر الصحية، باستخدام عمليات المحاكاة باستخدام طريقة النطاق الزمني للفرق المحدود و MATLAB. تكشف النتائج عن وجود اختلافات كبيرة في امتصاص الأنسجة، مع التركيز على الحاجة إلى تنظيم دقيق للتردد ومستوى الطاقة. ويسلط البحث الضوء أيضًا على التأثيرات البيئية، مثل التأثيرات الضارة على الحياة البرية مثل نحل العسل والطيور. وبشكل عام، فإنه يوفر بيانات مهمة لتطوير تقنيات اتصالات أكثر أمانًا وتوجيه المبادئ التوجيهية التنظيمية.

الكلمات المفتاحية: الموجات الكهرومغناطيسية، معدل الامتصاص النوعي للموجات SAR، طريقة الزمن لتفريق المحدد FDTD، الأنسجة البشرية، معادلة فريس

General introduction

Electromagnetic waves play a vital role in our daily lives, affecting the ways we communicate, access information, and interact with the surrounding environment. In this study, we define the electromagnetic wave with its properties plus the Maxwell's equations [1-5].

We have identified exposure systems for industrial electromagnetic waves that help understand the effect of electromagnetic waves on biological samples [7]. Exposure systems are usually in vivo or in vitro [7], [8].

Additionally, we mentioned to the sources of daily exposure to waves, including natural and artificial [9-11]. Moreover, the effect of electromagnetic waves on the environment such bees, animals, birds, as well as plants is also presented based on works in [12-15].

The study also addresses various effects on the human body, including thermal and non-thermal [16-18], with an introduction to the 2020 guidelines.

In this study, we are focused on the computation of the specific absorption rate (SAR) for six layers of the human head include: skin, fat, bone, dura, CSF, and brain. The electrical database of the head layers are inspired from woks in [20-23]. Typical values taken from a study using a mobile phone at 900 MHz and 1800 MHz frequencies [24-27]. We supported our results with a source code that calculates values the received power and the attenuation during propagation, at a distance of 1000 meters from the emitter for three different frequencies: 900 MHz, 1800 MHz, and 2400 MHz. This helps us to understand the effect of electromagnetic waves with the variation of frequency. Moreover, we modelled the thermal interaction between the electromagnetic waves at 900 MHz and 1800 MHz with three layers of the human head (skin, bone, and brain) based on the FDTD method [28], [29].

The results show that the specific absorption rate (SAR) is highly related to the field intensity. At high frequencies the field attenuation is high; then we can use high frequencies to attenuate the power. As the distance increases the attenuation increases as well. The best way for avoiding the effect of electromagnetic waves is by staying away from any radiating sources, such as cell phones, BTS, relays, antennas and so on. This makes us safer as possible from any electromagnetic radiation.

The manuscript is organized as follows:

Chapter one summarises the electromagnetic waves theory. The electromagnetic wave has a very important role in our daily life with shaping the way that we communicate, access information, and interact with our surroundings, and is a form of energy that travel through the space in the form of oscillating electric and magnetic fields.

The second chapter presents the impact of electromagnetic waves on the environment. Alongside the benefits they provide, there is growing concern about their potential impact on the environment. This chapter explores the diverse effects of electromagnetic fields on wildlife, including insects, birds, animals, and plants.

The third chapter presents the impact of electromagnetic waves on the human health. Electromagnetic waves, both ionizing and non-ionizing, interact with biological systems in various ways, raising questions about their effects, ranging from immediate thermal damage to long-term risks like cancer and neurological disorders.

The last chapter aims to evaluate the SAR values in human head layers based on electric field strength measurements. Also, the attenuation and the received power versus distance with different cell phone frequencies are studied and discussed. As well as, the effect of the frequency on the attenuation is also studied and discussed. We end our work with a general conclusion, by summarizing the main results of this work.

Chapter 1: Electromagnetic Waves

1.1.Introduction

The Electromagnetic wave has a very important role in our daily life with shaping the way that we communicate, access information, and interact with our surroundings, and is a form of energy that travel through the space in the form of oscillating electric and magnetic fields. This phenomenon known as electromagnetic radiation encompasses a wide range of wavelengths and frequencies.

1.2. Definition of the Electromagnetic wave

An electromagnetic wave made from an electric field and magnetic field, which propagate through the space; those two fields are perpendicular to the direction of the propagation and vary periodically around a zero average.

Electromagnetic waves and signals result from variations in electric and magnetic which are transmitted in the speed of the light (**c=3*10^8 m/s**), they are also transmitted in material environments by being attenuated there [1].

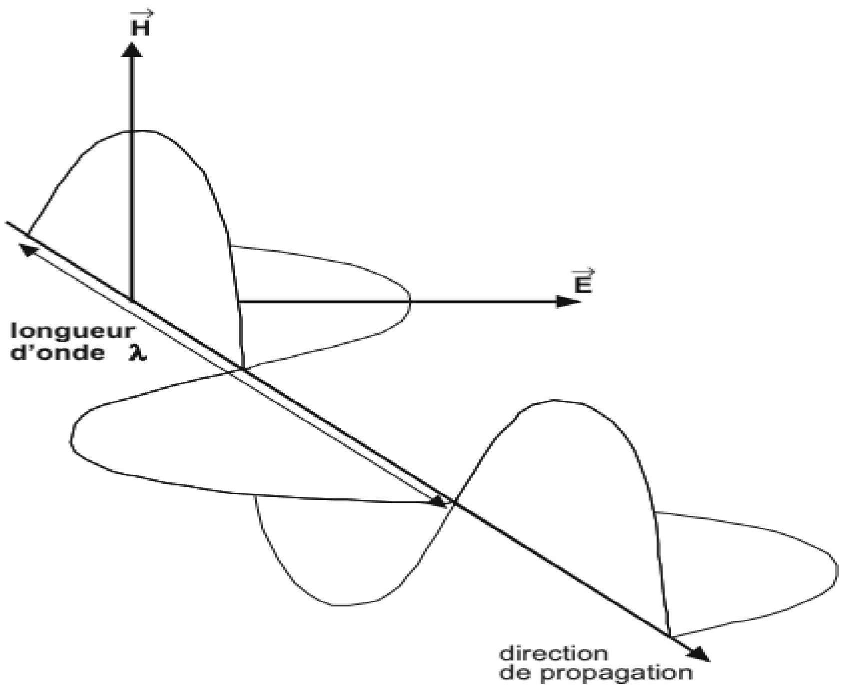

Figure 1.1: Schematic representation of an electromagnetic wave [1]

These are only transverse waves. Only differences in frequency make it possible to classify them.

1.3. Properties of the electromagnetic waves [2], [3]

1.3.1. Frequency

The frequency of the OEM is that two fields (electric and magnetic) which compose it, it is also the frequency of the current following in the antenna.

Example: a sinusoidal signal of 100MHz, applied to a transmitting antenna will produce electric field and magnetic field vary sinusoidally at the frequency of 100 MHz

1.3.2. The electromagnetic wavelength

The wavelength is a distance travelled by a wave in one period. [20]

$$\lambda = c \times T = \frac{c}{f} \tag{1.1}$$

With

λ**:** The wavelength

c**:** light speed

T**:** the period

f**:** frequency

1.3.3. Propagation

The electromagnetic waves propagate from the transmitting antenna to the receiving antenna in various ways:

- By a direct wave, starting from the transmission on the receiver without encountering a naturel or artificial obstacle.
- By a reflected wave, when the wave encounters an obstacle it is sent back its entirety, or part of it, in a different direction.

1.3.4. Polarisation

The polarization of an electromagnetic wave is that of its electric field ($\vec{E}$), so the different types of polarization of an OEM are:

- If the electric field ($\vec{E}$) keeps a constant direction, we say that the polarization is rectilinear.
- The most saving electric field ($\vec{E}$) is the horizontal polarisation or the vertical polarisation.
- There are also the both of circular and elliptical polarisation.

1.3.5. Electromagnetic wave Spectrum

The electromagnetic wave spectrum represents the distribution of the electromagnetic waves according to their wavelength, their frequency or even their energy, this spectrum is showing up down below :

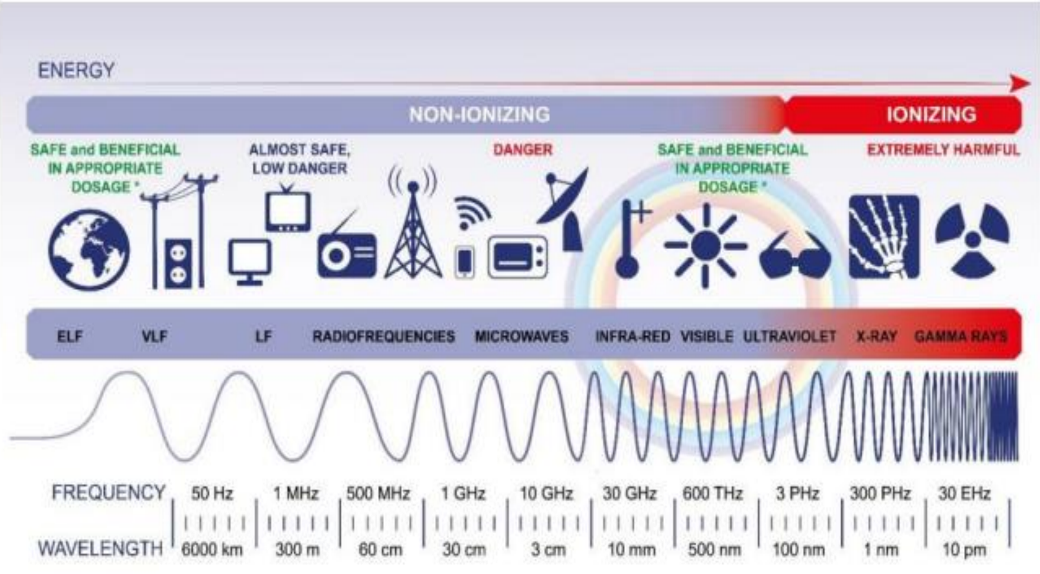

Figure1.2: Electromagnetic wave Spectrum [4]

1) Electromagnetic radiation

The electromagnetic spectrum consists of a different type's wave with a different wavelength and frequency; the following are the types of electromagnetic waves in the spectrum:

a) Radio wave

These waves compared to the other types of electromagnetic, they have a longest wavelength range from 100,00km to less than a meter, and they are invisible to our eyes.

We use the radio waves in:

- Communication system like the TV and broadcasting or mobile communication.
- Used by global positioning satellite.
- 20Hz to 2000Hz used by us to communicate with each other.
- The radio waves in ultrasonic region are used to detect the sea objects
- Ultrasound, which lies in the radio waves range, is used in medical science to detect several diseases. The ultrasonic waves are using also in cleaning the teeth.

b) Micro-waves

They are the higher frequency waves lying roughly between radio and infrared waves, and they are ranging from as long as one meter to as short as one millimeter. We use them in:

- Telecommunication satellite use the microwaves to transmit the voice through the phones.
- The initial use of the microwaves

c) Infrared

Located between the visible, invisible portions of the EM spectrum, which is between 750 nm to 1 mm. use in:

- Detect the ink
- Military applications of infrared waves include the target acquisition
- Night vision
- Homing and tracking
- Industrial factory
- Shorts ranges wireless communication

d) Visible light

Visible light is the most familiar form of electromagnetic radiation, for example, the sun is a natural source of the visible waves, and visible light is visible to human eyes.

e) Ultraviolet

The atmosphere's ozone layer blocks some of the UV rays .they are divided into three categories: UV-A, UV-B, UV-C, the UV-A has a longest wavelength and it is less dangerous; UV-B is of intermediate wavelength and causes the sunburned and long period of exposure, skin cancer; UV-C has a very short wavelength and kills bacteria and virus.

f) X-Rays and Gamma Rays

The X-Rays are very high-energy light waves. Gamma rays are extremely low, they are both similar to each other and both of them are an example of the ionizing radiation.

2. Radiation types

a) Ionizing radiation

Ionizing radiation has so much energy it can knock electrons out of atoms, a process known as ionization. Ionizing radiation can affect the atoms in living things, so it poses a health risk by damaging tissue and DNA in genes. Ionizing radiation comes from x-ray machines, cosmic particles from outer space and radioactive elements. Radioactive elements emit ionizing radiation as their atoms undergo radioactive decay.

a) Non-ionizing radiation

Non-ionizing radiation has enough energy to move atoms in a molecule around or cause them to vibrate, but not enough to remove electrons from atoms. Examples of this kind of radiation are radio waves, visible light and microwaves.

The energy of the radiation shown on the spectrum below increases from left to right as the frequency rises.

1.4. Application of Electromagnetic waves [2-3]

Electromagnetic wave are widely used in broadcasting, telecommunications, industrial application, medical field Which are produced by electrical equipment and play a crucial role in wireless communication. New advancements in radio-communication continue by using the electromagnetic waves increasingly complex transmission systems.

1.4.1. Industrial applications [5]

There are countless applications for electromagnets, ranging from large-scale industrial machine to small electronic components.

- Used for heating and drying (the microwave heating systems use a high power electromagnetic wave source with a frequency of 2.45 GHz)
- Remote sensing and radiolocation.
- Another application in the industrial sector is the induction heating system, which is generated heat on a metal support placed in a variable magnetic field at a frequency of approximately 40 KHz; the magnetic field emits electromagnetic waves in the surrounding medium.

Notice: It may happen some of emitting or leak of electromagnetic from the electrical equipment however, those things will be organised by the CEM (Electromagnetic Compatibility) standards.

I.4.1.radiocommunication [5]

Many applications, including broadcast and telecommunications services, use electromagnetic waves as means of transmitting and transferring information between transmitters and receivers.

The information is given (voice, image, and video). They are associated with different services (radio and television broadcasting, mobile telephone networks, telephone wireless, wireless autonomous (police, fire-fighters), Wi-Fi-internet access points, air and sea radar, walkie-talkies, home automation controls, cars, wireless alarm systems.

Many wireless systems use radio frequency transmitters are helping to measure ambient electromagnetic field levels in the environment.

For all these systems, in the case of a public exhibition, two-transmitter configuration must be distinguished:

1. Fixed radio-communication transmitters operating permanently: for example, radio and television broadcasting transmitter or antenna of mobile telephone base station.
2. portable transmitters which are sending from time to time and associated with specific uses, such as the talkie-warlike, cell phone, Wi-Fi cards on laptop .

We have that table down below which is representing the different services, applications and frequency bands used, down below:

Table 1.1: The different services, applications, and frequency bands used [5]

Frequencies bandwidths	Services/Application
9 kHz - 30MHz	– Long wave broadcasting, waves – medium and short waves – Avalanche victim detectors – Anti-theft detection systems – Contactless card reader – – Medical applications
30 MHz – 87.5MHz	– Analog television broadcasting and digital – Professional networks – (taxis, fire-fighters, police – national radio networks – independent) – Radio amateurs – Wireless microphones – Aeronautical radiolocation – Radars – Medical applications
87,5 - 108MHz	– Broadcasting in modulation of frequency
108 - 136MHz	– Aeronautical traffic management
136 - 400MHz	– Analog television broadcasting and digital – Professional networks – (police, fire-fighter, SAMU) – Frequencies reserved for free flight
400 - 470MHz	– Networks professionals (gendarmerie, SNCF, EDF) – Remote controls and medical telemetry – Control systems

	− TETRA and TETRAPOL cellular networks − Medical applications
470- 860MHz	− Analog television broadcasting and digital
860 - 880MHz	− ISM band (Industrial, Scientific, Medical): short range devices, type alarms, remote controls, home automation, wireless sensors, RFID
880 - 960MHz	− Mobile telephony (GSM 900)
960 - 1 710MHz	− Digital broadcasting − Private networks − Radio beams
1 710 - 1 880MHz	− Mobile telephony (GSM 1800)
1 880 - 1 900MHz	− DECT cordless phones
1 920 - 2 170MHz	− Mobile telephony (UMTS)
2 400 - 2 500MHz	− Wi-Fi networks − Bluetooth − Oven
3 400 - 3 600MHz	− Broadband radio local loop (WiMAX)
> 3 600MHz	− Radars − Local radio loop − Radio beams

1.5. Equations of Maxwell [5]

1.4.1. Descriptions of Maxwell equations

This equations Represent the relations between electric charge, electric current, electric field and magnetic field, in four expression to describe the vast world of electromagnetic. The Maxwell equations translated from different theorems in local form **(Gauss, Ampère, and Faraday)**

1.5.2. Integral form of Maxwell's equations

Maxwell-Gauss equation

The distribution of the electric charges is the cause of the electric field. The electric flux across the Gaussian surface surrounding volume in a direct form with the electric charge inside.

Integral form

$$\iint_{dv} \overrightarrow{E}.\mathrm{d}\overrightarrow{S} = \iiint_{V} \rho dV = Q(V) \quad (1.2)$$

Local form

$$\overrightarrow{\nabla}.\vec{E} = \frac{\rho}{\varepsilon_0} \quad (1.3)$$

Maxwell-Thomson equation

Magnetic field lines form a closed loop. The magnetic flux crossing the surface closed volume is equal to the magnetic charge inside (null), because there are no magnetic monopoles.

Integral form

$$\oint \oint \vec{B}.\overrightarrow{ds} = 0 \quad (1.4)$$

Local form

$$\overrightarrow{\nabla}.\vec{B} = 0 \quad (1.5)$$

Maxwell-Faraday equation

A varying magnetic field the time produce (induced) an electric field. Electric circulation through a section ∂A of zone A is equal to the inverse variation of the magnetic flux through the same surface. The two field are perpendicular to each other.

Integral form

$$\oint_{dA} \vec{E}.\, d\vec{l} + \left(\iint_S \frac{\partial \vec{B}}{\partial t}.\, d\vec{S}\right) = 0 \quad (1.6)$$

Local form

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad (1.7)$$

Maxwell-Ampère equation

We can get the magnetic field from the moving of the electric or changing current, the circulation magnetic in a section ∂A of zone A is equal to the sum of current and the temporal variation of the current through this section.

Integral form

$$\oint_{dA} \vec{B}.\, d\vec{l} = \left(\iint_S \frac{\partial \vec{B}}{\partial t}.\, d\vec{S}\right) = \iint_S \vec{J}_t \,.\, d\vec{S} + \left(\iint_S \frac{\partial \vec{E}}{\partial t}.\, d\vec{S}\right) \quad (1.8)$$

Local form

$$\vec{\nabla} \times \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t} \quad (1.9)$$

In short [5], Maxwell's equations indicate that electric and magnetic fields propagate at a certain speed and interact based on the strength of the electric field generated by a moving magnet. This speed is considered the speed of light, and Maxwell concluded that light waves are the product of electromagnetic waves. Heinrich Rudolf Hertz's experiments confirmed the existence of these waves and formed the basis for the theoretical basis of radio waves and radar devices that we use today.

1.5.3. Differential form of Maxwell's equations [5]

$$\vec{\nabla}.\vec{E} = \frac{\rho}{\varepsilon_0} \quad (1.10)$$

The advection of the electric field is proportional to the density of charge.

$$\vec{\nabla}.\vec{B} = 0 \quad (1.11)$$

The advection of the magnetic field is zero and there is no monopole magnetic.

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad (1.12)$$

A variation of the electric field in one direction (towards the left) gives the inverse temporal variation of the magnetic field on the axis vertical.

$$\vec{\nabla} \times \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t} \tag{1.13}$$

The variation of the magnetic field in one direction is equal to the sum of the electric field and its variation over time.

1.6. Wave equations [3]

The fields propagate in an isotropic medium and Homogeneous, so we have that with constant e and μ. Let us suppose that there are either charges or free currents in the medium (it is a non-conductive medium): $\rho = 0$, $j = 0$.

1.7. Poynting vector [5]

A quantity describing the magnitude and direction of the flow of energy in electromagnetic waves, represent by:

$$\vec{P} = \frac{\vec{E} \wedge \vec{B}}{\mu 0} \tag{1.14}$$

1.8. Maxwell's equation in harmonic regime [5]

They are given by the following expressions:

$$\vec{\nabla} . \vec{B} = 0 \tag{1.15a}$$

$$\vec{\nabla} . \vec{D} = \rho \tag{1.15b}$$

$$\vec{\nabla} \times \vec{E} = -j\omega\vec{B} \tag{1.15c}$$

$$\vec{\nabla} \times \vec{E} = \vec{j} + \frac{\partial \vec{D}}{\partial t} \tag{1.15d}$$

1.9. Conclusion

In conclusion, electromagnetic waves are integral to our understanding of the universe and crucial to modern technology. These waves, consisting of electric and magnetic fields oscillating perpendicular to each other and to the direction of propagation, travel at the speed of light through space and various materials. Maxwell's equations beautifully describe their generation, propagation, and interaction, illustrating how electric charges and currents give rise to these waves.

The electromagnetic spectrum encompasses a wide range of frequencies and wavelengths, each serving unique purposes in communication, medical imaging, industrial applications, and scientific research. From the familiar radio waves used in broadcasting to the high-energy gamma rays employed in medical diagnostics and industrial inspection, each segment of the spectrum offers distinct advantages and challenges.

Applications of electromagnetic waves continue to expand, driving innovations in telecommunications, remote sensing, healthcare, and beyond. As our understanding of these waves deepens, so too does our ability to harness their potential for the benefit of society. Moving forward, advancements in electromagnetic wave technologies promise further breakthroughs in communication systems, medical treatments, and scientific exploration, shaping a future where these waves play an increasingly vital role in everyday life.

Chapter 2: The impact of the electromagnetic waves on the environment

2.1. Introduction

The electromagnetic field is a fundamental aspect of our modern world, permeating both natural and artificial environments. From the Earth's magnetic field to the radiofrequency radiation emitted by telecommunications devices, electromagnetic fields play a significant role in our daily lives. However, alongside the benefits they provide, there is growing concern about their potential impact on the environment. This chapter explores the diverse effects of electromagnetic fields on wildlife, including insects, birds, animals, and plants. Through examining various studies and experimental findings, we aim to shed light on the complex interactions between electromagnetic radiation and the environment, highlighting both the potential risks and the need for further research and regulation to ensure the preservation of our ecosystems.

2.2. The main exposure systems

2.2.1. General information on exposure systems [7]

Through this study [7], we summarize how to design an exposure system based on some of the requirements mentioned below:

<u>Electromagnetic requirements</u>

The exposure system is an essential element since it allows the generation of an electromagnetic field for the detection of biological and animal specimens. The system is designing under the requirements represented by Figure 2.1.

<u>Electromagnetic requirements</u>

The principal elements that make up an experimental montage that RF (signal (frequency, form)) source and the exposure system. The exposure system should be adapted to it characteristics of the electromagnetic signal used. The problem is transmission signalling from the source to the biological sample with minimal loss, Figure 2.2.

For a good transmission, the exposure system must have characteristic impedance equal to the source impedance, generally 50 Ohms for RF signals.

If the exposure system has a different characteristic impedance, it is possible to observe a standing wave phenomenon and the load does not absorb part of the energy. This part of energy is reflected back to the source, Therefore, A fortiori, it does not apply to our biological sample. Generally.

In all cases, we have to ensure that the energy delivered by the source is applied to the biological sample.

Exposure systems are characterized by their interaction that is compatible with the specific absorption rate, which is related to the level of energy provided by the radio frequency generator.

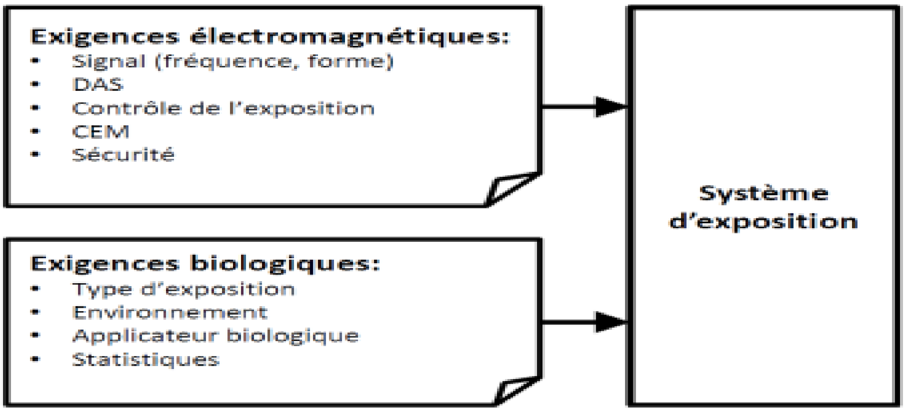

Figure 2.1: Conception of the exposition system [7]

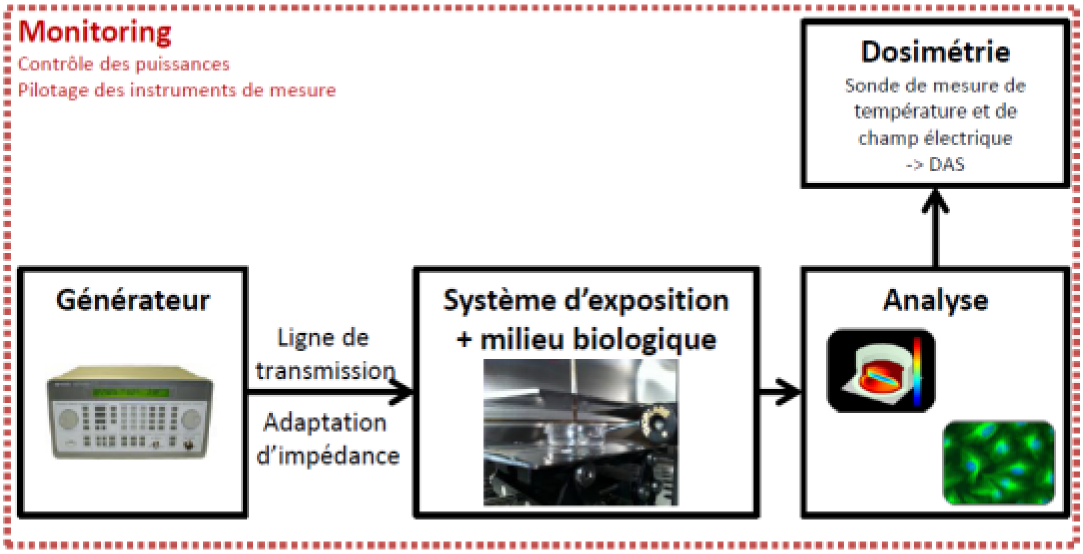

Figure 2.2: General display of experimental montage [7]

Parameters (of incident and reflected forces, or even temperature) are monitored during exposure experiments in real time, using measuring devices equipped with probes (for energy, temperature, and Electric field (usually controlled by computer).

Biological requirements

The exposure system has to adapt to biological requirements such as (temperature conditions, carbon dioxide concentration or even strict sterility). Some incubator models have holes in the walls to allow cables or sensors to pass through. The cells are cultured in containers in which the exposure system must also be adapted. The exposure system envisaged must also allow exposure of a sufficient number of cells or animals to obtain useful statistics on the results.

2.2.2. Review of in vitro exposure systems

These systems divide into three main categories [7], [8], which are:

2.2.2.1. The radiative systems

These systems rely on antennas that emit electromagnetic radiation onto biological samples.

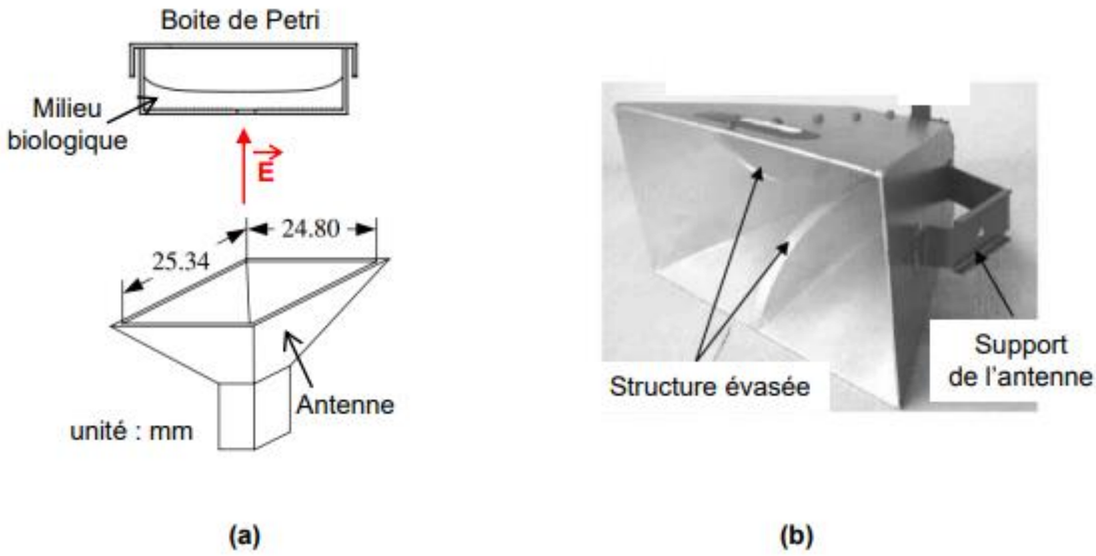

Figure 2.3: Exposure system based on a horn antenna: (a) diagram of a horn antenna used to expose a biological medium in a Petri dish, (b) photo of a horn antenna [8]

2.2.2.2. The propagation systems

The propagation systems based on the lines the transmissions generate an electric field between the line and the mass; we take an example of the propagation systems of exposure from [7]:

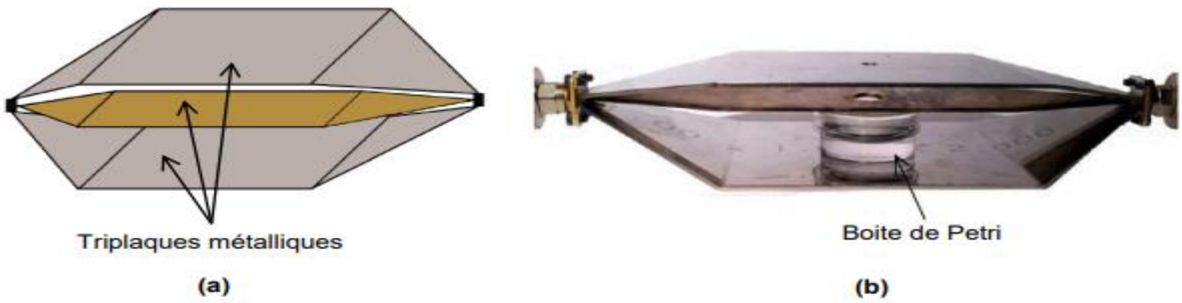

Figure 2.4: Exposure system based on a TEM cell: (a) schematic of a TEM cell, (b) photo of a TEM cell containing a Petri dish filled with a biological medium [8]

2.2.2.3. The resonant systems

They are cavities in which standing waves exist creature. [8], among the resonant systems, we can mainly retain short-circuited waveguides, Shorted waveguides are closed, compact resonant structures.

They can be easily placed in an incubator when strict environmental control is necessary to ensure cell viability during long experiments. They are characterized by small dimensions and by their high efficiency in terms of the high amount of power absorbed, but the positioning of the sample is critical, due to the extremely localized regions of field uniformity [8].

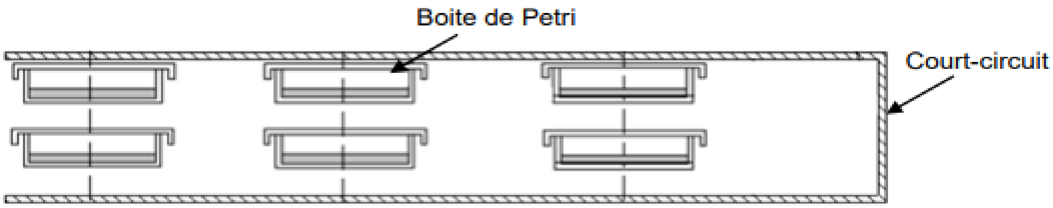

Figure 2.5: Exposure system based on a short-circuited waveguide containing several boxes of Petri dishes filled with biological medium [8]

The short-circuited waveguide [7]

short-circuit waveguides were used, short-c ircuiting at 1,800MHz. In general, short-circuit waveguides, such as rectangular and circular waveguides; allow tubes and Petri dishes to be exposed to different frequencies, which facilitates the study of the electromagnetic effect on biological samples, depending on the dimensions. Guide.

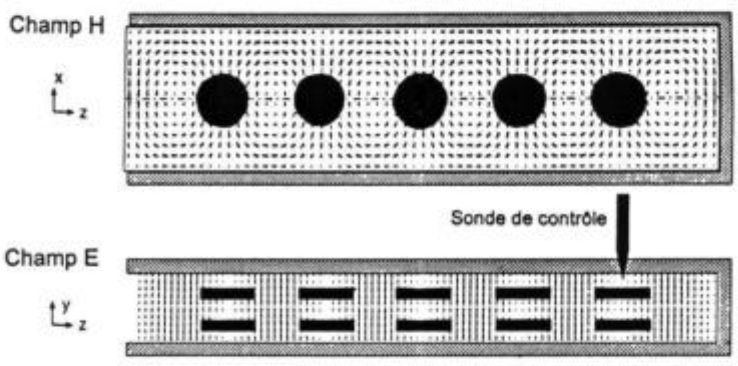

Figure 2.6: Placement of Petri dishes in a short-circuited waveguide [7]

The wire-plate cell

This one has been developed by Laval as it said her [7], efficient additions of eight Petri dishes whose open structure facilitates temperature uniformity in the system for placement in the incubator. It is important to note that the bandwidth of such a narrow structure is therefore relatively restricted in terms of the bandwidth of the wire plate cell. However, the adaptive system makes it easy to overcome this allergy.

2.2.3. In vivo exposure systems [7]

Animal shadowing is an essential step in understanding the interactions of living organisms, Electromagnetic waves with living organisms. For these, a certain number of systems, the gallery is also used. There are two main types, “whole body” and "localized".

2.2.3.1. Whole body exposure systems

As part of the vivo whole body exposure studies (design that can simulate the real exposition in life), different systems used to expose animals (biological sample) to the electromagnetic fields like:

- The TEM cell was used in studies conducted by e A. Saran et al. , G. Grafström and al. and de J. L'Eberhardt and al., it allow exposure of the entire body of the animal.
- The Ferris-Wheel used for example in B-D studies. Görlitz et al., working at GSM 900 or DCS 1800 frequencies, and D. Yu et al. at 900MHz. This exposure system is a radial cavity where the electromagnetic field is produced at the help of a driver placed in its center.

2.2.3.2.Localized exposure systems

It is the exposure of biological samples to electromagnetic waves in a specific and targeted manner, for example, we have:

The carousel is one of those exposure-localized systems; it uses a dipole antenna placed on the centre of carousel, a few centimetres of the animal's noses, which is allowed to localized exposure of the head.

2.3. Exposure sources on general

2.3.1. The naturel electromagnetic environment [9], [10]

The first exposure that we face in our daily life is the earth's electromagnetic field that exist in the nature, it has a value of approximately 50 μT (micro tesla), and this field have nothing to do in the terms of their influences with the artificial alternative fields.

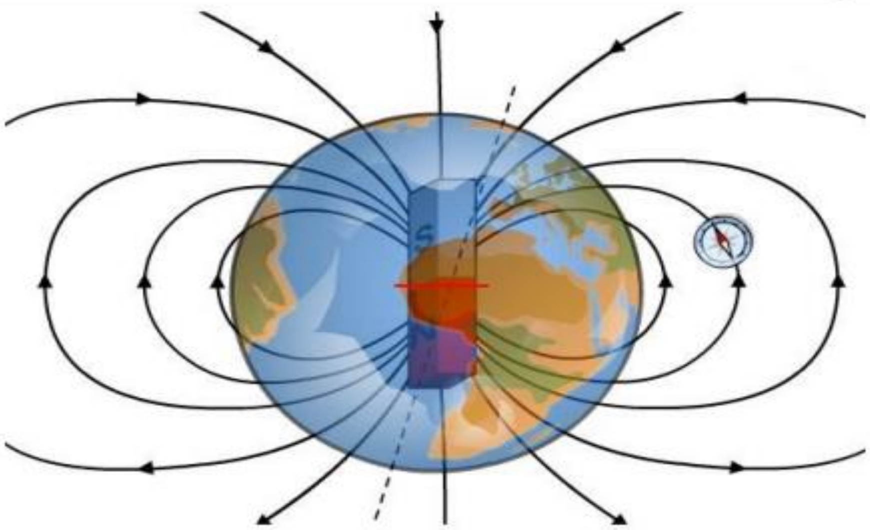

Figure 2.7: Representation of the Earth's magnetic field [10]

The sun

The first and most intense natural source of EMF is the sun. Figure 8 shows the distribution of solar energy as a function of wavelength and therefore frequency, with a maximum intensity found in the visible range (400-800 nm).

The Earth's atmosphere covers both of X and Y radiation are the most active and dangerous to human life, but they are more dangerous than radio radiation.

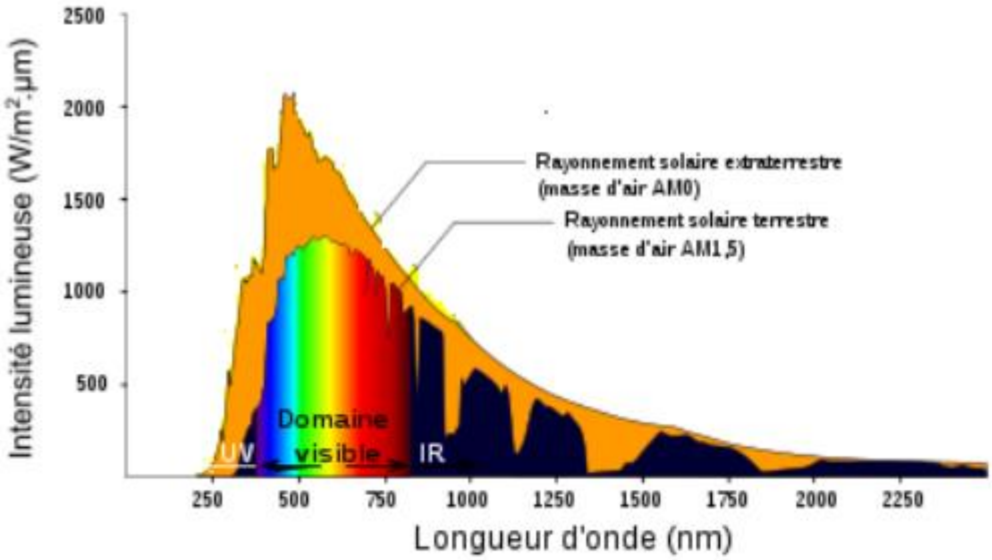

Figure 2.8: Solar spectrum on earth and in space [9]

2.3.2. The artificial electromagnetic environment

Through [9], [10], [11], [12], we find that the sources of exposure lie where there are sources of transmission and reception or devices that rely on electromagnetic waves in their work in general, and in the following we mention some of them:

1).Telecommunications: such as broadcasting, mobile phones, base station, Mobile phones, antennas, or wireless communications.

- Mobile phones transmit with variable powers, depending on the network (GSM, UMTS, LTE, etc.) and the reception level of the base station. For example, the maximum mobile transmission power in the GSM and UMTS case is around 250mW and 200mW for LTE.

- The following drawing shows the peak exposure near an antenna at a distance of one meter, which is much higher than the peak exposure at ground level (therefore it is recommended to be present Within a circumference of less than two meters .

2).the mobile phone relay antenna: they emit continuously, they have a power and reach variable depending on the extent and the characteristic of the geographical area that they serve.

Classes of the relay antennas were standardized by organizations international. Which we did put some type of them in the table [11] down below:

Table 2.1: Relay antenna classes according to INRS 'National Institute for Research and Security [11]

antenna	**“macro” antennas**	**“macro” antennas**	**“Pico” antennas**	**“femto” antennas**
Power	Long range whose injected power is greater than 6.3 W.	Medium range whose injected power is between 250mW and 6.3mW.	Of local range whose injected power is included between 100mW and 250mW.	Residential range whose injected power is less than 100mW.
Use in	They are found on high points, such as building roofs, pylons or water towers.	They are used indoors or outdoors. We find them for example on street furniture	They are used, for example, as repeaters within certain companies.	They are mainly found in private homes.

Radio relays (FH) [11]

These are very directive antennas, which emit continuously. The frequencies used vary from 1.3GHz to 86GHz. it possible to establish a point-to-point connection over long distances (several tens of km). The mobile telephone operators use this antenna to connect relay antennas and the core network. They have the advantage of avoiding the installation of a wired or optical link when this proves difficult or too expensive. The transmitting power of the antennas is generally between 100mW and 1W.

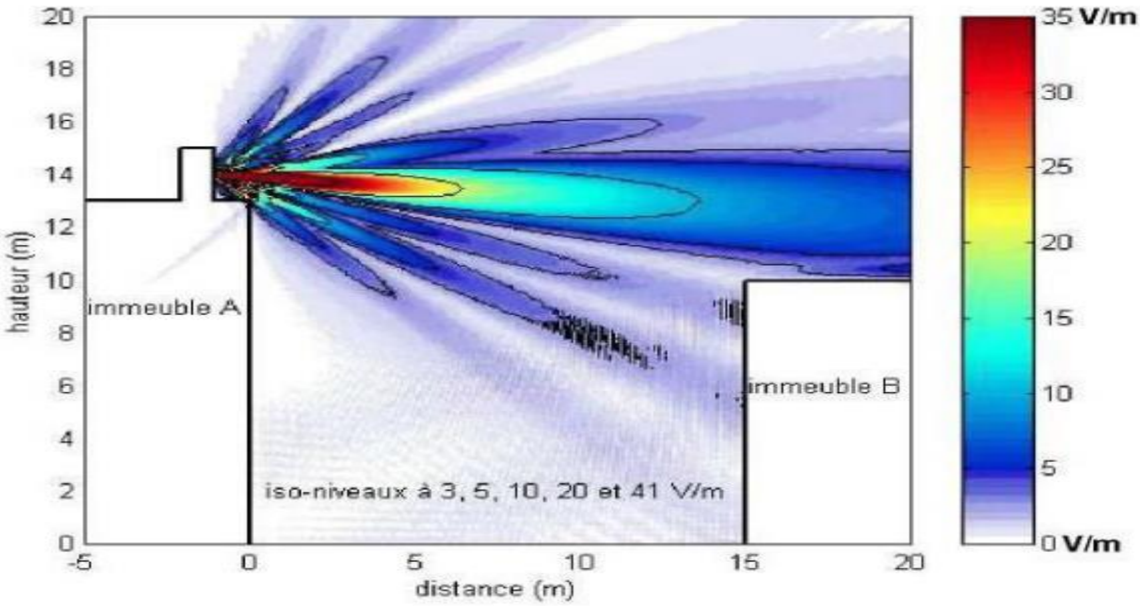

Figure 2.9: Peak exposure to contact with a relay antenna according to Alain GEST's report [9]

2.4. Impact of the electromagnetic waves on the environment

The impact of the electromagnetic fields on the wildlife, particularly honeybees and birds, is growing concern.

Honeybees exposed to 50 Hz electric fields show changes in biochemical markers, while radiofrequency radiation form mobile phones disrupts bird navigation and animal health, these findings highlight the urgent need to understand and mitigate the effects of the electromagnetic fields on the ecosystem.

2.4.1. Wilde life

Provide a brief overview of how exposure standards established for human safety might relate to wildlife.

2.4.2. HoneyBee

2.4.2.1. Effect of the electric field at 50 Hz

2.4.2.1.1. Experimental design of the study

In the study [12], we do have wooden cages (200 × 150 × 70 mm) with two Feeders (5 ml each). Each cage contained 100 workers of 1-day-old honeybee workers with giving the honey-unrestricted access to a sucrose solution with a concentration of 1 mole/ dm^3. Each of the control and the experimental groups consisted of 10 cages.

The 50 Hz E-field with the intensity of 5.0, 11.5, 23.0, or 34.5 kV/m exposed to the experimental groups of a 2-day-old worker bees for 1, 3, 6, or 12h.

For the control groups the measurement of the electric field in their area was <1.0 kV/m the control groups were marked with the letter C and number of hours of exposure corresponding to the experimental groups exposure duration.

The selected E-field parameters result from the possible exposure of the honeybee to the electromagnetic field in nature. 50 Hz is a widely used power frequency in the world. Worker bees were flying at a height of about 2 meters near the power line is exposed to an E-field with an intensity up to 2–10 kV/m. High obstacles in the worker’s way caused flight at a high of about five or more meters, then the bee is exposed to an E-field intensity even up to 12–15 kV/m. The time, which bees can spend in the environment while searching the feed, varies between 1 to up to 6h. 12h exposure was chosen to check linearity of the phenomenon.

2.4.2.1.2. E-field setup

<u>The following steps do the electric field steps</u>

1. Form of a plate capacitor, a homogeneous 50 Hz E-field generated in the exposure system.
2. Fixed field intensities at 5.0 kV/m, 11.5 kV/m, 23.0 kV/m, or 34.5 kV/m.

3. Maintaining changes in E-field homogeneity and stability within ±5% in the emitter, to ensure consistency.
4. Verified field intensity and homogeneity through LWiMP accredited testing lab, employing ESM-100-meter No. 972153.
5. Confirmed calibration with certificate LWiMP/W/070/2017 (LWiMP an accredited testing laboratory) from PCA AP-078 calibration lab, dated 15/02/2017.
6. Conducted measurements at specified points within the empty emitter, using a 10 x 10 x 5cm, 3-mesh configuration.
7. Maintained E-field stability through continuous monitoring of applied voltage via control circuit (Figure 2.4).

2.4.2.1.3. Analyse of the sample

In this study after the after the end of exposure to the E-field from 100 bees from each group, they took immediately hemolymph samples, to collect hemolymph, we removed the bee's antennae with sterile tweezers and gently pressed the bee's body.

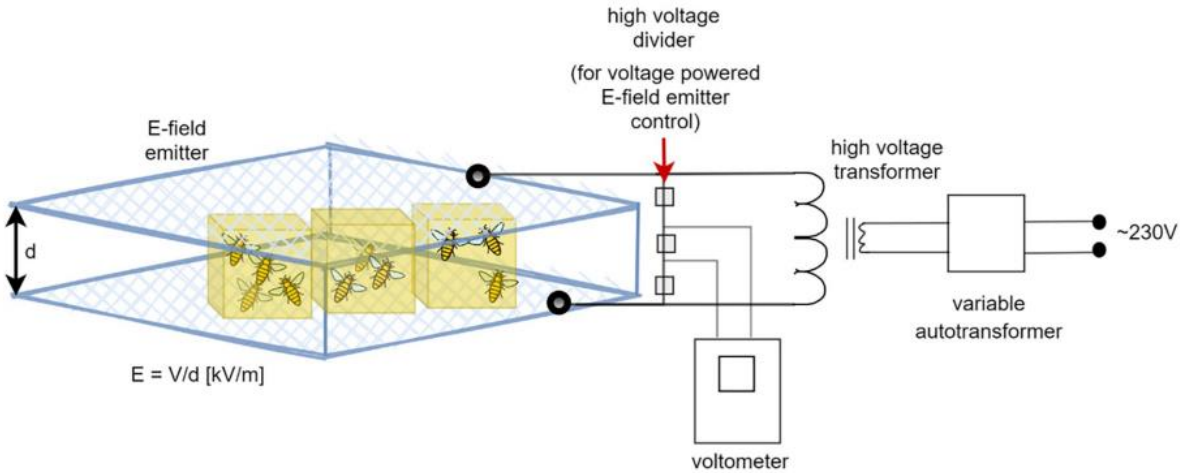

Figure 2.10: Exposure of bees to the E-field at 50 Hz and variable intensities in laboratory conditions. [12]

2.4.2.1.4. Results of the exposition on the honeybee

The following table shows the results:

Table 2.2: Effects of Electromagnetic Field (E-field) Exposure on Enzymatic and Non-Enzymatic Markers in Bee Hemolymph [12]

	Control group	Experimental group
For the enzymatic biochemical marker (AST, ALT, and ALP)	- There is no difference in their activity**.**	- All groups exhibited lower enzymatic activity then the control groups**.** - Longer exposure times resulted in further reductions in enzymatic activity. - Bees exposed to the highest E-field intensity (34.5 kV/m) for 12 hours showed the lowest enzymatic activity. - The 11.5 kV/m group for 1 hour displayed the highest enzymatic activity among experimental groups.
Non-Enzymatic Antioxidant Concentration (Albumin and Creatinine):	1. No difference in albumin and creatinine concentration.	- Albumin concentration increased with longer exposure times to E-field intensities of 5.0 and 11.5 kV/m. - Creatinine concentration decreased with longer exposure times, significantly after 3 hours of exposure to E-field. - No significant changes in albumin and creatinine concentration observed after 1 hour of exposure. - After 3 hours or more of exposure, creatinine concentration decreased while albumin concentration increased compared to control groups.

2.4.3. Mobile Phone Radiations and Its Impact on Birds, Animals [13]

Under the influence of radio frequency radiation, our ecosystem is always affected, as this radiation can cause serious effects such as genetic defects, genotoxicity, and behavioural changes in insects, birds and animals, affecting their ability to survive and reproduce.

2.4.3.1. On animal

The animals experienced chronic exposure to microwave and radiofrequency radiation from various sources such as GSM and UMTS/3G cordless phones, base stations, wireless local area networks (WLAN), wireless personal networks (WPAN) such as Bluetooth, and digital enhanced wireless communications (DECT).

As in humans, radiofrequency stimulates biological stimulation effects on biomolecules that include changes in:

2. For intracellular ionic concentration, cellular proliferation, interventions in the immune system
3. the effects on animals' reproductive ability
4. Effects on stress hormones in intrauterine development, genotoxic effects, effects on the nervous and circulatory systems, and the number of births decreased
5. Numerous studies have pinpointed cellphone towers as a potential cause in the decline of animal populations
6. Probably caused a suffering in the deterioration of health and changes in behaviour
7. an aversive behavioural response in bats
8. Frequent deaths in domestic animals; such as, hamsters and guinea pigs, living near mobile telecommunication base stations have been witnessed
9. exposed to electromagnetic field strength greater than 2 V/m cause Causes a decrease in the bat activity
10. Decreased in a bat colony (Tadarida teniotis) , when several phone masts were placed 80m from the colony
11. Reduced fertility in male rats and dystrophic changes in the reproductive organs of female rats

2.4.3.2. Effects of Radiation on Birds

little is known about the effects of long-term exposure experienced by birds near mobile phone base stations., however the extensive using of cell phones Public debate on potential harmful effects ,When birds are exposed to weak electromagnetic fields, they become disoriented and start flying in all directions, which explains why migratory birds undermine their navigational abilities.

Microwave radiation emitted from communications towers causes them to collide and causes the death of millions of migratory birds every year, There have been dramatic declines, almost to the point of extinction in Glasgow, Hamburg, Dublin, Belgium, etc.

75% of chicken embryos that were exposed to a GSM mobile phone during incubation died compared to 16%, who were not exposed to any radiation. Eggs laid in nests near the towers do not hatch; there has been a mysterious decline in the number of house sparrows, which in itself indicates that the urban ecosystem will see some environmental changes that are unfavourable to human health in the near future.

In light of current knowledge, there is sufficient evidence that there are serious impacts of this technology on the biosphere. The World Health Organization has classified radiofrequency electromagnetic radiation as a probable carcinogen (Category 2B), the same classification used for lead, chloroform, and automobile emissions. Cell phone subscriptions totaled over 6 billion in 2013, which resulted in a global penetration rate of 93.1% per 100 inhabitants. By contemplating these serious statistics, one can easily conclude that almost every part of the biosphere is exposed to increasing RF radiation continuously, so the electromagnetic interaction of radio waves with biological system needs to be quantitatively evaluated.

2.4.4. Plants and the electromagnetic waves

2.4.4.1. The impact of electromagnetic fields (EMFs) on plants

This article [14] providing touches on various studies and hypotheses regarding the potential impacts of electromagnetic fields (EMFs) on the environment, which are:

- Health of Plants and Trees: EMFs have the potential to affect the health of plants and trees, particularly those located near sources like phone masts. This impact could include changes in growth patterns, altered photosynthesis rates, and increased vulnerability to environmental stressors such as drought or disease.

- Deterioration of Plant Health: Exposure to EMFs might contribute to the deterioration of plant health over time. This could manifest as stunted growth, reduced yield in crops, or increased susceptibility to pests and pathogens.

- Effects on Reproduction: EMFs could also influence the reproductive processes of plants, potentially leading to reduced seed germination rates, altered flowering times, or disruptions in pollination dynamics.

- Long-Term Implications: The long-term consequences of EMF exposure on plant communities are not fully understood but could have implications for ecosystem stability, biodiversity, and ecosystem services provided by plants, such as carbon sequestration and soil stabilization.

3.3. Effects of exposure to electromagnetic radio waves (Physiological effects) [15]

Chlorophyll Concentration: Prolonged exposure to RF-EMFs has been observed to decrease chlorophyll concentration in plants, indicating potential harm to their photosynthetic capabilities.

Growth Inhibition: Exposure to RF-EMFs can inhibit the growth of plant roots, coleoptiles, and overall biomass, as evidenced by reduced dry weight and lengths of various plant parts. For instance, exposure of maize seedlings to 1800 MHz (power density 332 to 10.36 mW/m^2) RF-EMFs for 4 hours resulted in significant reductions in root and coleoptile growth.

Germination Rates: RF-EMF exposure has been linked to slowed germination rates in plants, affecting both the radical and plumule stages of development. For example, exposing Vigna radiata seeds to RF-EMFs from mobile phones (power density 8.55 W/cm^2, 900 MHz) for 2 hours or longer significantly slowed down germination rates.

Oxidative Stress: RF-EMF exposure induces oxidative stress in plants, leading to increased lipid peroxidation, hydrogen peroxide buildup, and alterations in enzyme activity related to stress response.

Enzyme Activity: RF-EMF exposure influences the activity of various enzymes in plants, such as proteases, amylases, polyphenoloxidases, and peroxidases, which are involved in metabolic processes and stress responses.

Stress-Related Enzymes: Plants exposed to RF-EMFs exhibit hyperaccumulation of stress-related enzymes, suggesting an intensified stress response compared to non-exposed plants.

Effects on Plant Physiology: RF-EMF exposure impacts various physiological processes in plants, including carbohydrate and protein breakdown, enzyme activity, and signal molecule release. For example, exposure to 1800 MHz RF-EMFs for extended durations caused comparable increases in amylase and invertase activity, and decreases in starch phosphorylase activity in maize seedlings.

Considerations for Mobile Phone Towers: Given the observed harmful effects on plant growth and development, the potential impacts of RF-EMFs on healthy plants should be considered before erecting mobile phone towers.

Need for Further Research: While preliminary studies indicate the vulnerability of plants to RF-EMFs, more comprehensive research is needed to understand the mechanisms and potential long-term effects. For instance, studies have shown increased specific absorption rate (SAR) values in plants exposed to RF-EMFs, particularly with changes in fruit shape.

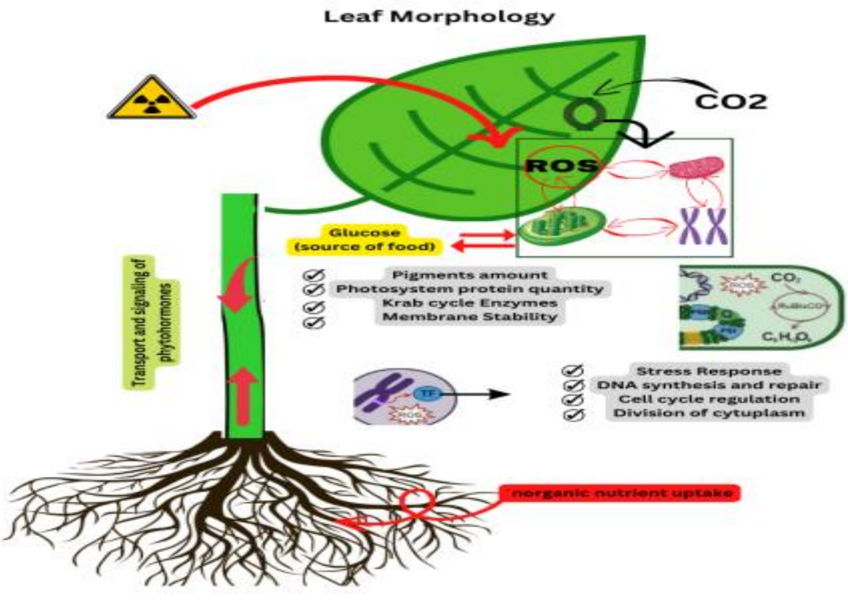

Figure 2.11: Detrimental impacts of radiations on plant physiology [15]

2.5. Conclusion

In conclusion, the impact of electromagnetic fields on the environment is a multifaceted issue that warrants careful consideration. From the design of exposure systems to the effects on various organisms, including honeybees, birds, animals, and plants, it is evident that electromagnetic radiation can have significant implications. While research indicates potential adverse effects such as changes in enzymatic activity, reproductive issues, and alterations in plant physiology, there is still much to be understood about the long-term consequences.

As we continue to advance technologically and increase our reliance on electromagnetic devices and infrastructure, it becomes increasingly important to conduct thorough research to better understand the interactions between electromagnetic fields and the environment. By doing so, we can develop strategies to mitigate potential risks and ensure the sustainability of our ecosystems. Additionally, incorporating precautionary measures and regulations based on scientific evidence can help safeguard the health and well-being of all living organisms in our environment.

Chapter 3:

The impact of the electromagnetic waves on the human health

3.1. Introduction

In the modern era, humanity's reliance on electromagnetic technologies is ubiquitous, from wireless communications to medical diagnostics. However, alongside these advancements comes a growing concern over their potential impact on human health. Electromagnetic waves, both ionizing and non-ionizing, interact with biological systems in various ways, raising questions about their effects, ranging from immediate thermal damage to long-term risks like cancer and neurological disorders. Understanding these impacts requires a nuanced exploration of both the thermal and non-thermal mechanisms through which these waves influence human biology. This discussion delves into the intricate interplay between electromagnetic radiation and human health, examining the spectrum from acute radiation syndromes to chronic health implications, and highlights the ongoing research efforts aimed at safeguarding public health in an increasingly wireless world.

3.2. The impact of the electromagnetic waves on the human

3.2.1. Thermal effects on the body [16]

1. Eye Damage

Microwave waves can inflict serious damage to the cornea due to their ability to be absorbed, particularly since the cornea lacks a mechanism for temperature regulation.

2. Skin damage

When microwave waves do not exceed 10 GHz, they stay on the body's surface and are absorbing by the skin, potentially causing burns.

3. Ear damage

Prolonged exposure to mobile phone waves can result in the sensation of extra sounds due to temperature changes in brain tissues, leading to pressure waves being transmitted to the inner ear.

4. Brain Damage

Mobile phone waves can affect the skin on the upper level of the skull, with areas near the phone being more affected.

5. Decreased Fertility in Men

Testicles, sensitive to heat and harmful waves, can experience temporary or permanent sterility due to absorption of radio waves.

6. Increase in Body Temperature

Electromagnetic waves can lead to an increase in body temperature.

3.2.2. Non-Thermal Effects on the body [16]

1. Neurodegenerative Diseases

Electromagnetic waves, especially from mobile phones, are associated with neurodegenerative diseases like Alzheimer and Parkinson, independent of temperature changes.

2. Other Disorders

Non-thermal side effects of radio frequencies include headache, dizziness, convulsions, changes in heart rate rhythm, and anxiety during sleep, loss of concentration and memory, migraine, distraction, and increased blood pressure.

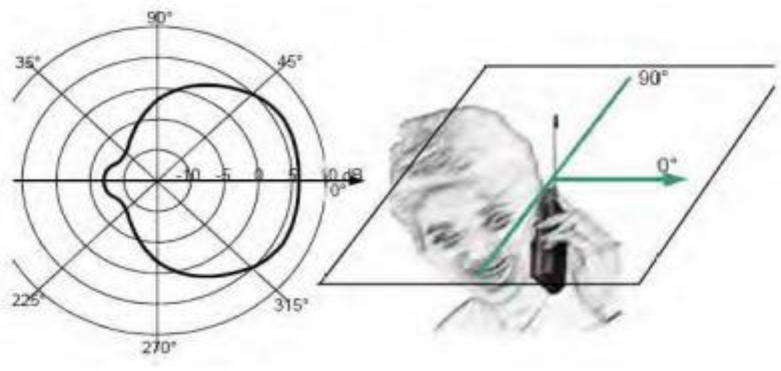

Figure 3.1: Radiation of electromagnetic waves near the human head [16]

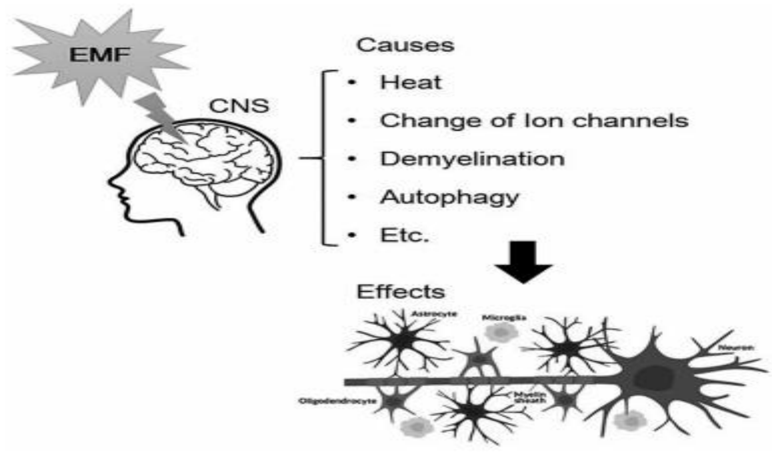

Figure 3.2: Schematic summary of the possible mechanisms of RF-EMF exposure in central nervous system [17]

3.3. The Health Effects of Ionizing Radiation on the human body [18]

Here is a brief overview of the effects of ionizing radiation on human health, including acute radiation syndrome, long-term impacts, DNA damage, radiation doses, therapeutic uses, and emerging treatments.

3.3.1. Acute Radiation Syndrome (ARS)

Caused by exposure to high doses of radiation in a short time. It progresses through several stages:

- Prodromal Stage**,** Symptoms like nausea, vomiting, and respiratory distress appear within minutes to days.
- Latent Stage, A period of apparent well-being, but internal damage progresses.
- Manifest Illness Stage**,** Depending on the syndrome (e.g., bone marrow, gastrointestinal, cardiovascular/central nervous system), severe symptoms manifest.
- Recovery or Death, Severe cases can result in death within months, while survivors may experience prolonged recovery over weeks to years.

3.3.2. Long-Term Effects

- Cancer**,** Long-term exposure to lower doses of ionizing radiation can increase the risk of cancers, particularly lung cancer due to radon exposure.

- **Genetic Mutations**

  Improper DNA repair can lead to mutations and chromosomal abnormalities, potentially causing cancer and genetic disorders in future generations.

- **Radiation-Induced Fibrosis**

  Excessive collagen production and reduced tissue flexibility, affecting various organs and significantly impairing quality of life.

- **Radiation Pneumonitis**

  Inflammation of lung tissue, leading to chronic respiratory issues.

3.3.3.DNA Damage

- **Direct Damage**

  Ionizing radiation can directly ionize DNA molecules, causing breaks in the DNA strands.

- **Indirect Damage**

  Radiation can ionize water molecules, producing free radicals that damage DNA indirectly. Approximately two-thirds of radiation-induced DNA damage is due to these free radicals.

3.4. ICNIRP 2020 Guidelines for Electromagnetic Field Exposure

The 2020 guidelines from the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [18] introduced significant changes to the reference levels (RL) compared to the 1998 guidelines. Here is a summary of the main updates and differences:

3.4.1.Averaging Time and Exposure Frequency

3.4.1.1. Averaging Time

- I**CNIRP 1998**: Whole-body exposure reference levels were averaged over 6 minutes.
- **ICNIRP 2020**: The averaging time for whole-body exposure has been extended to 30 minutes.

3.4.2. Frequency Range for Reference Levels

- **ICNIRP 1998**: Reference levels for electric and magnetic field strength were provided for frequencies up to 300 GHz.
- **ICNIRP 2020**: Reference levels for electric and magnetic field strength are now specified for frequencies up to 2 GHz, and for incident power density for frequencies between 2 GHz and 300 GHz.

3.4. Conclusion

In conclusion, the study of electromagnetic waves' impact on human health reveals a complex landscape and still studying where scientific understanding is continually evolving. From the direct thermal effects observed in tissues exposed to high-frequency waves to the subtler, potentially long-term risks associated with chronic exposure to lower frequencies, the spectrum of health impacts demands diligent investigation and regulatory vigilance. As technology advances, so too must our knowledge and strategies for mitigating potential risks. Continued research, stringent safety standards, and informed public discourse are essential to navigating the evolving intersection of electromagnetic technologies and human biology, ensuring that innovations enhance our lives while safeguarding our health for generations to come.

Chapter 4: SAR evaluation's values of the human head layers according to electric field strength measurements

4.1. Introduction

Given the increasing use of mobile phones, which exposes humans to more electromagnetic fields, it is crucial to study their impact on biological tissues. The level of radiation and the absorption in small, highly conductive areas of biological tissues can negatively affect health.

Cell phone usage comes with many health risks. Studies show that cell phone emissions can be very harmful, causing genetic damage, tumors, memory loss, higher blood pressure, and a weaker immune system. The fact that this radiation is invisible, intangible, and enters and leaves our bodies without us knowing makes it even scarier [20].

This study aims to evaluate the SAR values in human head layers based on electric field strength measurements. The attenuation, received power versus distance are studied and discussed. As well as, the effect of the frequency on the attenuation is also studied and discussed.

4.2. Definition of Specific Absorption Rate (SAR)

Specific Absorption Rate (SAR) is a dosimetric quantity, which defined as the rate of RF power absorbed per unit mass by any part of the body [21].

SAR value typically is specified at the maximum transmission power. Transmission power will be higher when the mobile phone used in the area with a very low field strength of received signals, because this represents the highest level of RF (radiofrequency) energy exposure that a user might experience during typical usage.

The quantity of electromagnetic radiation absorbed per mass with a specified time, which is defining as the Specific Absorption Rate (SAR) that can be calculated as [22]:

$$SAR = \sigma \frac{E^2}{\rho} \tag{4.1}$$

Where:

σ is the electric conductivity of the sample (tissue) in S/m,
E is the value of electric field strength in V/m,
ρ is the density of the sample in kg/m^3 .

4.3. The electromagnetic properties of human tissues [23]

Those properties are represent on both of the relative permittivity and conductivity, in the table down below, we will represent the properties of human model layers at the different frequencies:

Table 4.1: Properties of human model layers [23]

	permittivity (F/m)			Conductivity (S/m)		
Layers	**900MHz**	**1800MHz**	**2400MHz**	**900MHz**	**1800MHz**	**2400MHz**
Layer1 (skin)	41.4	38.9	38.1	0.87	1.18	1.44
Layer2 (fat)	5.46	5.34	5.29	0.051	0.078	0.102
Layer3 (Bone)	12.45	11.8	11.41	0.14	0.28	0.385
Layer4 (Dura)	44.4	42.9	42.1	0.96	1.32	1.64
Layer5 (CSF)	68.7	67.2	66.3	2.41	2.92	3.41
Layer 6 (Brain)	45.8	43.5	42.6	0.77	1.15	1.48

Table 4.2: Density of the layers of the human head model [23]

Tissue	Skin	Fat	Bone	Dura	CSF	Brain
ρ(kg/m^3)	1100	920	1850	1050	1060	1030

4.4. Electric field strength values

4.4.1. Assessments of the electric field values caused by mobile phone

This study [24] explores the impact of mobile phones by assessing the electric fields they generate around our heads. Our objective is to use these electric field values as a basis for calculating the Specific Absorption Rate (SAR) in a six-layer head model. We observed that older 2G phones with higher power emitted stronger electric fields compared to newer models. Notably, the strongest fields were near the ear, diminishing with distance. This indicates that stronger phones affect larger head areas, thereby influencing SAR calculations for various layers of the head model.

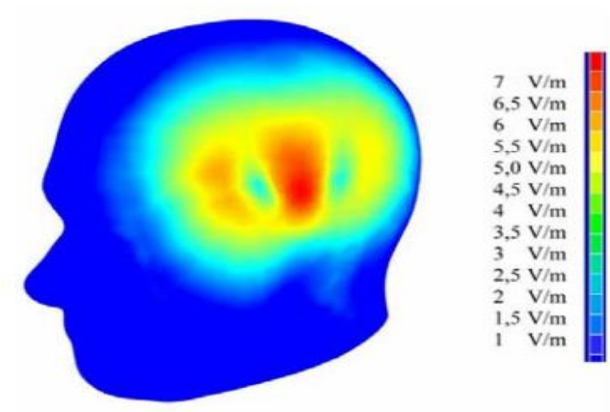

Figure 4.1: electric field distribution on the head for a power 0.8 W, frequency 900 MHz values during phone talk [24]

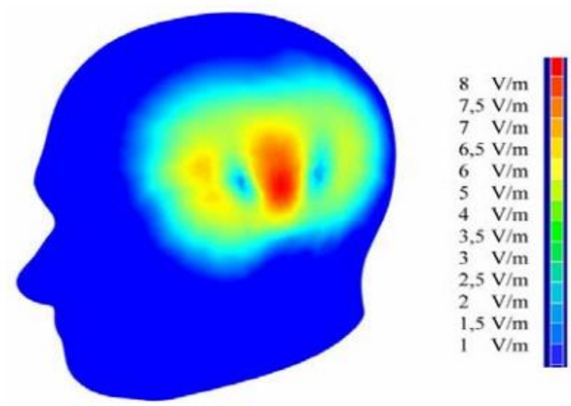

Figure 4.2: the electric field distribution on the head for a power 1w, frequency 1800 MHz values during phone talk [24]

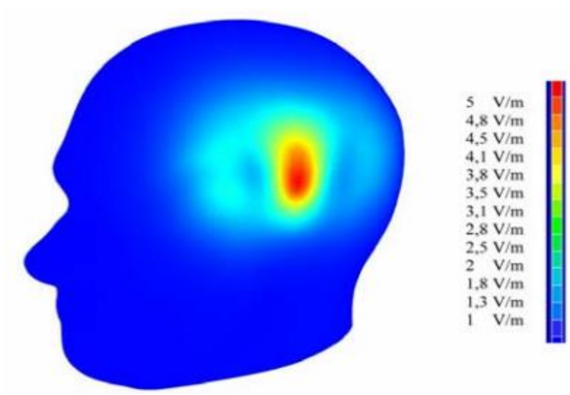

Figure 4.3: the electric field distribution on the head for a power 0.25, frequency 1800 MHz [24]

4.4.2. The results according to the study [24]

4.4.2.1. The electric field created by mobile phone for

4.4.2.1.1. For the figure 4.1 of a power 0.8 W, frequency 900 MHz

- (colour red) reaches 6–7V/m around the ear in a 3cm radius
- (colour yellow) the electric field strength is lower (4–5V/m) in a 4–5 cm radius
- (colour green) the electric field strength is 2–3V/m at a distance of 5-10cm radius
- (light blue colour) the electric field strength is about 2V/m at the upper part of the head
- Then decreases to 1V/m.

4.4.2.1.2. For the figure 4.2 of a power 1 W, frequency 1800 MHz

- (Colour red) reaches 6–8 V/m around the ear also in a 3 cm radius
- (colour yellow) the electric field strength is lower (5 V/m) in a 4–5 cm radius
- (colour green) the electric field strength is 2–4 V/m in 5–10 cm radius
- (light blue colour) In the upper part of the head electric field strength is about 2–4V/m
- at both sides of the head or on top of it the electric field strength is decreasing to 1V/m

4.4.2.1.3. For the figure 4.3 of a power 0.25 W, frequency 1800 MHz

- (Colour red) reaches 4–5 V/m around the ear in the radius 1.5 cm
- (Colour yellow) the electric field strength is lower (3.8 V/m) in radius 1.5–2 cm
- (Colour yellow green) the electric field strength is 2–4 V/m at the distance of 2–3 cm radius
- In the upper part of the head, (blue colour) electric field strength is about 1 V/m

4.4.2.1.4. Electric field strength of four mobile phone

The work in [24], providing a review research on the effect of the electromagnetic field of a cell phone on the human body, by taking the measurements of punch of cell phone (iPhone6 , iPhone 6s , Xioami note 4, etc.).

In this experiment, they were using NADRA measuring devices, to collect the data that we conclude in:

Table 4.3: the electric field strength measurement for a four mobile phone [25]

The standard	The mobile phone	The measurements (V/m)
GSM1800 MHz	Xioami Note 4	2.79
GSM1800 MHz	iPhone 6s	0.75
LTE 2400MHz	Honor 9	6.16
LTE 2400MHz	iPhone 6	0.72

4.5. Calculation of the SAR theatrical for the layers human head model using

4.5.1. MATLAB definition

MATLAB is a programming language and environment designed for numerical computation, data analysis, and visualization. It is widely used in engineering, science, and other fields for its powerful matrix operations and extensive library of mathematical functions, for the simulation, we used the version 2024.

4.5.2. Results

According to the values electric field that range from 1-7 V/m, which is created by mobile phone for maximum transmitted power equal 0.8W and frequency of 900MHz , the specific absorption rate in the layers of the head that calculate based on our code were:

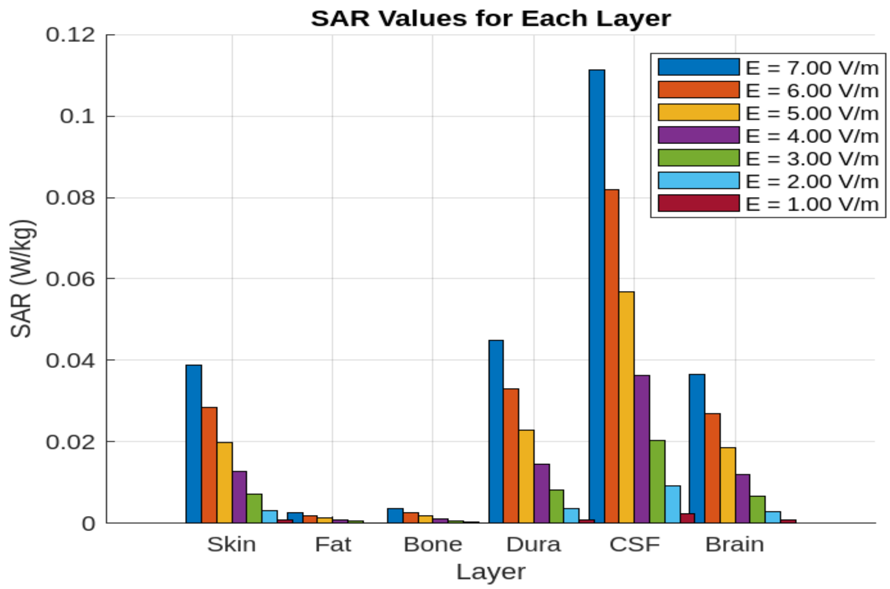

Figure 4.4: SAR level for the six layers of the head at 900MHz and transmitted power 0.8W

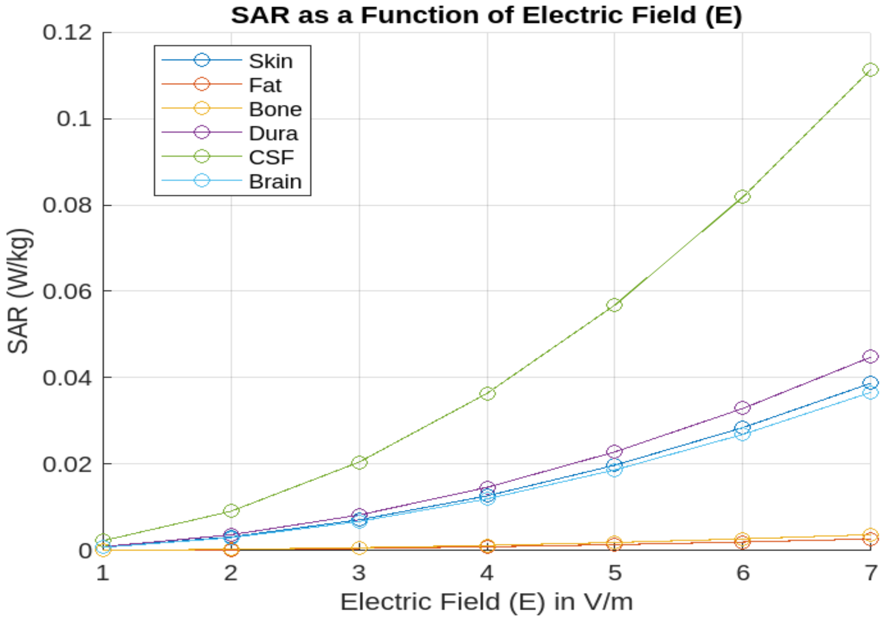

Figure 4.5: SAR of each layer's plot as a function of the electric field strength at 900MHz and transmitted power 0.8W

Table 4.4: the SAR values results according to the electric field strength created by mobile phone for a maximum transmitted power 0.8W and frequency at 900MHz

Electric field strength (V/m)	Layers of the head model	SAR of each layers
7 V/m	Skin	0.0388
	Fat	0.0027
	Bone	0.0037
	Dura	0.0448
	CSF	0.1114
	Brain	0.0366
The average SAR	for the 6-layer head model (7 V/m)	0.0397
6 V/m	Skin	0.0285
	Fat	0.0020
	Bone	0.0027
	Dura	0.0329
	CSF	0.0818
	Brain	0.0269
The average SAR	for the 6-layer head model (6 V/m)	0.0397
5 V/m	Skin	0.0198
	Fat	0.0014
	Bone	0.0019
	Dura	0.0229
	CSF	0.0568

	Brain	0.0187
The average SAR	for the 6-layer head model (5 V/m)	0.0202
4 V/m	Skin	0.0127
	Fat	0.0009
	Bone	0.0012
	Dura	0.0146
	CSF	0.0364
	Brain	0.0120
The average SAR	for the 6-layer head model (4 V/m)	0.0130
3 V/m	Skin	0.0071
	Fat	0.0005
	Bone	0.0007
	Dura	0.0082
	CSF	0.0205
	Brain	0.0067
The average SAR	for the 6-layer head model(3 V/m)	0.0073
2 V/m	Skin	0.0032
	Fat	0.0002
	Bone	0.0003
	Dura	0.0037
	CSF	0.0091
	Brain	0.0030
The average SAR	for the 6-layer head model(2 V/m)	0.0032
1 V/m	Skin	0.0008
	Fat	0.0001
	Bone	0.0001
	Dura	0.0009
	CSF	0.0023
	Brain	0.0007
The average SAR	for the 6-layer head model (1 V/m)	0.0008

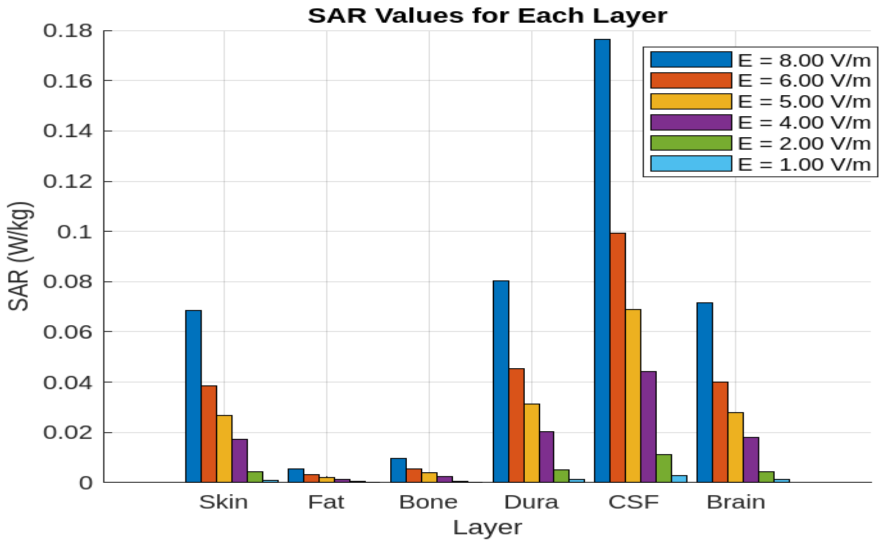

Figure 4.6: SAR level for the six layers of the head at 1800MHz and transmitted power 1W

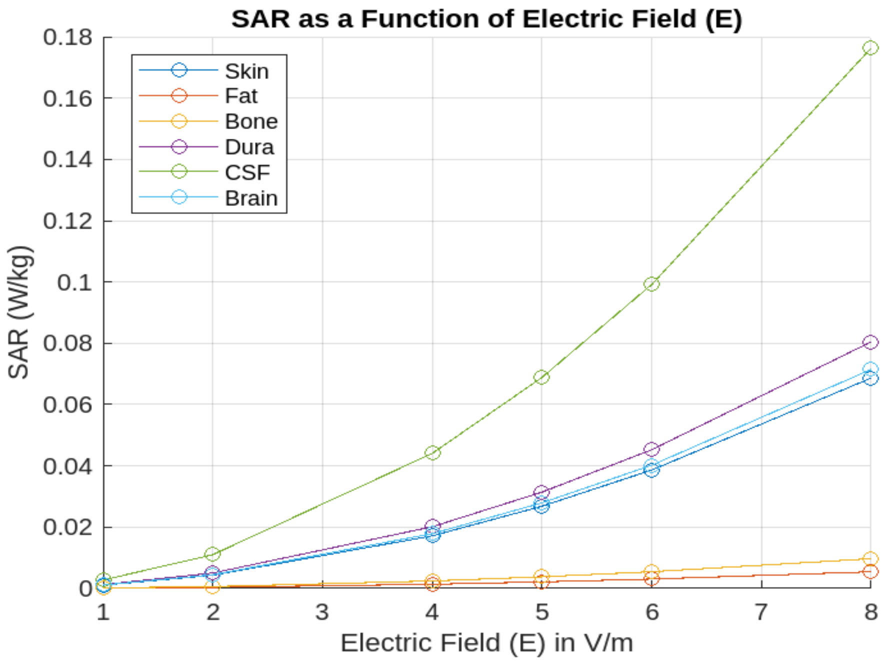

Figure 4.7: SAR of each layer's plot as a function of the electric field strength at 1800MHz and transmitted power 1W

Table 4.5: the SAR values results according to the electric field strength created by mobile phone for a maximum transmitted power 1 W and frequency at 1800 MHz

Electric field strength (V/m)	**Layers of the head model**	**SAR of each layers**
8 V/m	Skin	0.0687
	Fat	0.0054
	Bone	0.0097
	Dura	0.0805
	CSF	0.1763
	Brain	0.0715
The average SAR	for the 6-layer head model (8V/m)	0.0687
6 V/m	Skin	0.0386
	Fat	0.0031
	Bone	0.0054
	Dura	0.0453
	CSF	0.0992
	Brain	0.0402
The average SAR	for the 6-layer head model (6V/m)	0.0386
4 V/m	Skin	0.0172
	Fat	0.0014
	Bone	0.0024
	Dura	0.0201
	CSF	0.0441
	Brain	0.0179
The average SAR	for the 6-layer head model (4 V/m)	0.0172
3 V/m	Skin	0.0043
	Fat	0.0003
	Bone	0.0006
	Dura	0.0050
	CSF	0.0110
	Brain	0.0045
The average SAR	for the 6-layer head model(3V/m)	0.0043
2 V/m	Skin	0.0032
	Fat	0.0002
	Bone	0.0003
	Dura	0.0037
	CSF	0.0091
	Brain	0.0030
The average SAR	for the 6-layer head model(2V/m)	0.0032
	Skin	0.0011
	Fat	0.0001

1 V/m	Bone	0.0002
	Dura	0.0013
	CSF	0.0028
	Brain	0.0011
The average SAR	for the 6-layer head model (1V/m)	0.0011

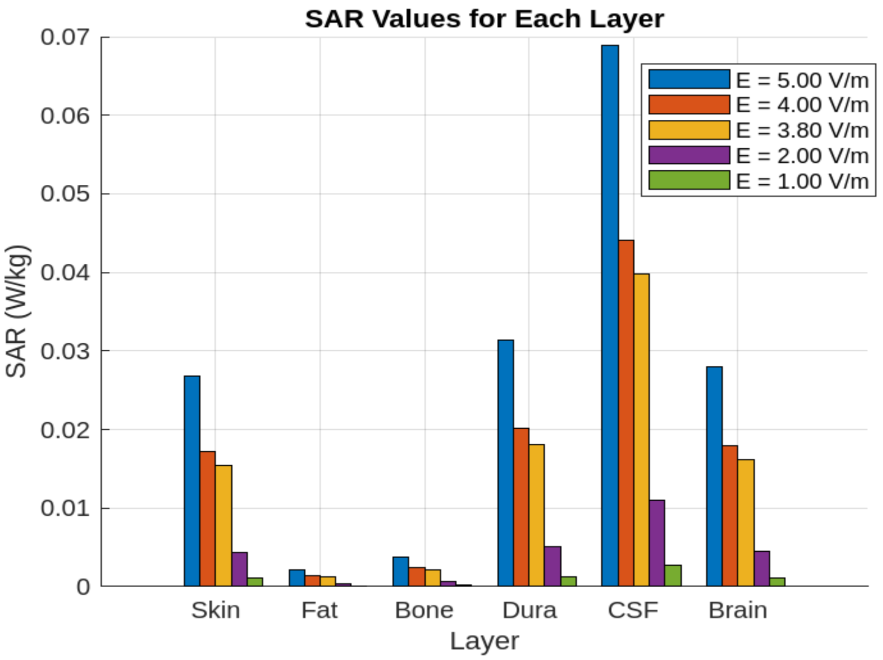

Figure 4.8: SAR level for the six layers of the head at 1800MHz and transmitted power 0.25W

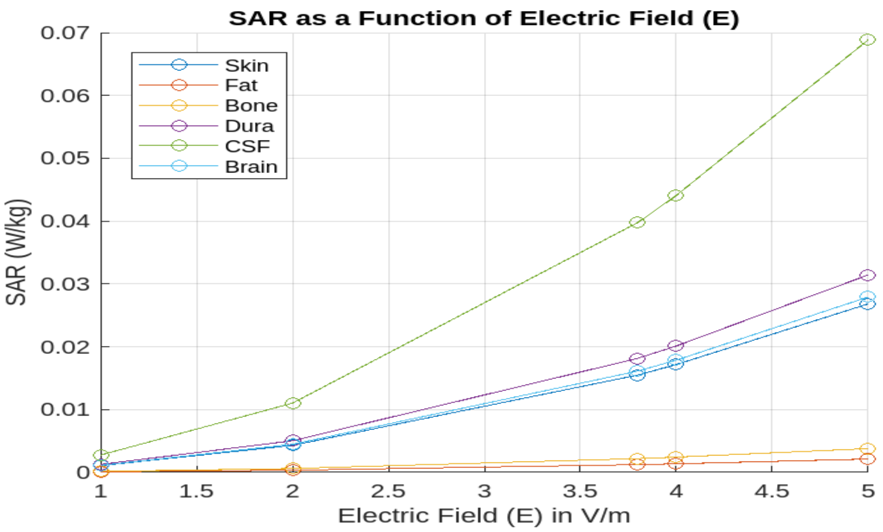

Figure 4.9: SAR of each layer's plot as a function of the electric field strength at 1800MHz and transmitted power0.25W

Table 4.6: the SAR values results according to the electric field strength created by mobile phone for a maximum transmitted power 0.25 W and frequency at 1800 MHz

Electric field strength (V/m)	**Layers of the head model**	**SAR of each layers**
5 V/m	Skin	0.0268
	Fat	0.0021
	Bone	0.0038
	Dura	0.0314
	CSF	0.0689
	Brain	0.0279
The average SAR	for the 6-layer head model (5 V/m)	0.0268
4 V/m	Skin	0.0172
	Fat	0.0014
	Bone	0.0024
	Dura	0.0201
	CSF	0.0441
	Brain	0.0179
The average SAR	for the 6-layer head model (4 V/m)	0.0172
3.8V/m	Skin	0.0155
	Fat	0.0012
	Bone	0.0022
	Dura	0.0182
	CSF	0.0398
	Brain	0.0161
The average SAR	for the 6-layer head model (3.8 V/m)	0.155
2 V/m	Skin	0.0043
	Fat	0.0003
	Bone	0.0006
	Dura	0.0050
	CSF	0.0110
	Brain	0.0045
The average SAR	for the 6-layer head model (2 V/m)	0.0043
1 V/m	Skin	0.0011
	Fat	0.0001
	Bone	0.0002
	Dura	0.0013
	CSF	0.0028
	Brain	0.0011
The average SAR	for the 6-layer head model(1 V/m)	0.0011

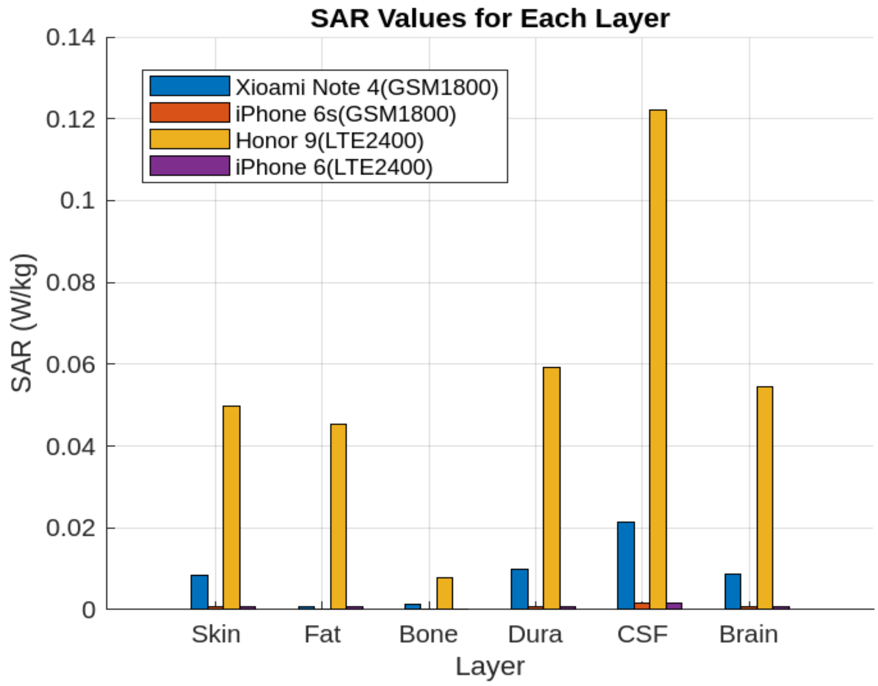

Figure 4.10 :SAR levels for a four mobile phone at 1800 MHz, 2400 MHz for the six layers of the head

Table 4. 7 : The SAR values results according to the electric field strength created by a four mobile phone

Mobile phone's type	Layers of the head model	SAR of each layers
Xioami note 4	Skin	0.0084
	Fat	0.0007
	Bone	0.0012
	Dura	0.0098
	CSF	0.0215
	Brain	0.0087
The average SAR	for the 6-layer head model (2.79 V/m)	0.0084
iPhone 6s(GSM1800)	Skin	0.0006
	Fat	0.0000
	Bone	0.0001
	Dura	0.0007
	CSF	0.0015
	Brain	0.0006
The average SAR	for the 6-layer head model (0.75)	0.0006
Honor 9(LTE2400)	Skin	0.0083
	Fat	0.0042
	Bone	0.0079
	Dura	0.0593
	CSF	0.1221

	Brain	0.0545
The average SAR	for the 6-layer head model (6.16 V/m)	0.0427
iPhone6(LTE2400)	Skin	0.0001
	Fat	0.0001
	Bone	0.0001
	Dura	0.0008
	CSF	0.0017
	Brain	0.0007
The average SAR	for the 6-layer head model (0.72 V/m)	0.0006

4.5.3. Observations

According to the results of our code, that's aimed to understand how factors like electric field strength, frequency, and tissue properties influence SAR levels, which are crucial for assessing potential health risks associated with exposure to electromagnetic fields.

First, and as we expected, we found that SAR generally increases with higher electric field strengths across all layers of the head model. This trend aligns with the basic principles of electromagnetic field interaction with biological tissues, where greater energy absorption occurs at higher field strengths.

Next, we examined the SAR values across different layers of the head model. Interestingly, we observed variations in SAR levels among the layers, which can be attributed to differences in tissue properties such as conductivity and density. For instance, tissues with higher conductivity tend to absorb more energy and consequently exhibit higher SAR values.

Moving on to the impact of frequency, our study considered two frequencies: 900 MHz and 1800 MHz, We found that SAR values tend to increase with higher frequencies, consistent with the known behaviour of electromagnetic fields. Additionally, we explored how transmitted power affects SAR levels and observed similar trends of higher SAR values with increased power.

4.5.4. Discussion

Let's discuss the implications of our findings. Understanding SAR values is crucial for establishing safety guidelines for wireless communication technologies, as it helps assess potential health risks associated with electromagnetic field exposure. By providing average

SAR values for different scenarios, our study contributes valuable insights for policymakers and regulators in setting safety standards.

In conclusion, our study highlights the complex interplay between electric field strength, frequency, tissue properties, and SAR values in the human head. By elucidating these relationships, we aim to contribute to the ongoing efforts to ensure the safety of wireless communication technologies.

Now, if we look at the figures, Figure 4.4 illustrates the SAR levels for the six layers of the head at 900MHz and a transmitted power of 0.8W. Meanwhile, Figure 4.5 presents the SAR of each layer as a function of electric field strength at 900MHz and 0.8W transmitted power.

For the frequency of 1800 MHz and transmitted power of 1W, Figure 4.7 showcases the SAR levels for the six layers of the head, while Figure 4.6 depicts the SAR of each layer as a function of electric field strength at 1800MHz and 1W transmitted power.

4.4. Evaluation the received power and the attenuation through the distance

In this part of the study, we would like to evaluate the received power and attenuation of the transmitters over the distance using the Friis equation. Understanding how distance, frequency, and emitting power affect the propagation of electromagnetic waves is vital to ensuring the effectiveness and safety of communications systems, especially when interacting with human tissue. Our base in this part was the following equations [26]:

4.4.1. The telecommunications equation (Friis formula)

$$P_r = P_e\, G_e G_r \left(\frac{\lambda}{4\pi d}\right)^2 \tag{4.2}$$

4.4.2. Link Attenuation

$$\alpha_l = \frac{P_r}{P_e} = G_e G_r \left(\frac{\lambda}{4\pi d}\right)^2 \tag{4.3}$$

4.4.3. Propagation Attenuation

$$\alpha_p = \left(\frac{\lambda}{4\pi d}\right)^2 \tag{4.4}$$

The Antenna's technical data that we going to use here were from [20], for the base station will operate an emitted power that reach to a 60 Watt or even to 100 Watt as a maximum, and for the gain here were going to suppose that $(G_e = G_r)$.

Where $G_e = 5$ dB [27] that is equal 3.162, so the results were:

Table 4.8: The received power and the attenuation values results through the distance

frequencies	Distances on meters	Attenuation on dB	Received power on dB
900 MHz	10	51.53	-23.75
	307.30	81.28	-53.50
	703.30	88.47	-60.69
	1000	91.53	-63.75
1800 MHz	10	57.55	-29.77
	307.30	87.30	-59.52
	703.30	94.49	-66.71
	1000	97.55	-69.77
2400 MHz	10	60.50	-32.27
	307.30	89.80	-60.02
	703.30	96.99	-69.21
	1000	100.05	-72.27

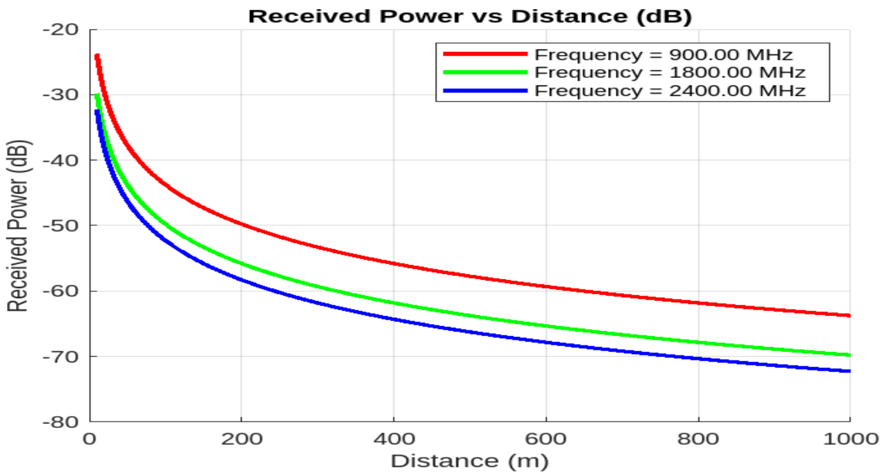

Figure 4.11: the received power through the distance

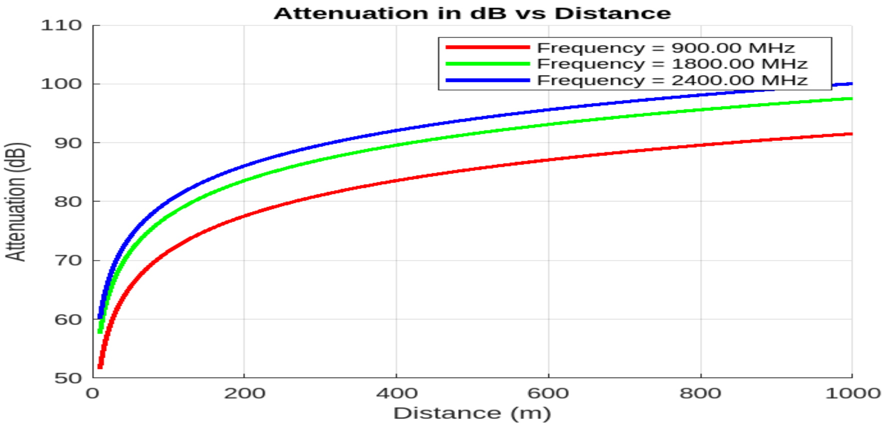

Figure 4.12: the attenuation of the signal through the distance

4.4.4. Discussion

4.4.4.1. Attenuation

As expected, for the frequency of 900 MHz, at the distance of 10 meters, the attenuation is 51.53 dB, as the distance increases to 1000 meters, the attenuation increases to 91.53 dB; this shows a significant increase in attenuation with distance.

For 1800 MHz, the attenuation is higher than 900 MHz at the same distances, with 57.55 dB at 10 meters and 97.55 dB at 1000 meters.

For the 2400 MHz, the attenuation is higher than both of the 900 MHZ and 1800 MHz, with 60.50 dB at 10 m and 100.05 dB at 1000 m , so here we can say for sure that as much as the frequency getting higher the attenuation getting bigger through the distances at the Figure 4-9 shows .

4.4.4.2. The received power

At 900 MHz, the received power at 10 meters is -23.75 dB, which is indicating a relatively strong signal. At 1000 meters, the received power drops to -63.75 dB, which is represent a significant loss of signal strength over the long distances.

At 1800 MHz, the received power at 10 meters is -29.77 dB, lower than that of 900 MHz due to higher attenuation. At 1000 meters, the received power further drops to -69.77 dB, showing a steeper decline with distance compared to 900 MHz

By compare to the 900 MHz and 1800 MHz, the received power for 2400 MHz is the lowest; at 10 meters is -32.27 dB, at 1000 meters, it decreases to -72.27 dB, indicating the most significant signal loss over distance.

As results, we can say that the higher frequencies result in higher attenuation and lower received power at the same distance. This is evident as we move from 900 MHz to 2400 MHz; the results confirm that higher frequency signals suffer greater free-space path loss.

The results highlights the critical relationship between distance, frequency, and received power in communication systems. As distance increases, attenuation significantly influences the received power, particularly at higher frequencies.

4.7. Simulate the interaction of the human head tissue with the electromagnetic waves using the FDTD method

In recent years, the proliferation of wireless communication devices has raised concerns about the potential health effects of electromagnetic (EM) wave exposure, particularly regarding the human head. This study aims to simulate the interaction between EM waves and human head tissue using the Finite-Difference Time-Domain (FDTD) method.

4.7.1. The FDTD method

The Finite-Difference Time-Domain (FDTD) method, developed by Kane Yee in 1966, is a numerical technique for solving complex electromagnetic problems where analytical solutions are not feasible. It transforms Maxwell's equations into explicit equations in the time domain using finite differences, allowing the calculation of electric and magnetic fields at specific points in a computational grid over time. This method provides a detailed time evolution of the electromagnetic field components throughout the domain.

In this study, I used MATLAB code based on the FDTD from a previous work [28] to achieve the study goal of simulating the interaction of electromagnetic waves with different human head tissues. This code provides a foundation for understanding the effect of electromagnetic waves on different tissues, which are the skin, bone and the brain at various frequencies.

4.7.2. The Bioheat Equation

In addition to the FDTD method, the bioheat equation is employed to model the thermal effects of electromagnetic wave exposure on tissues. The bioheat equation, formulated by Pennes in 1948, is given by:

$$\rho c \frac{\partial T}{\partial t} = \nabla(k.\nabla T) + (\rho c)_b \omega_b + (T_a - T) + q_m \quad (4.5)$$

Where:

ρ is the density of the tissue.

C is the specific heat

K is the thermal conductivity of the tissue

ω_b is the rate of blood perfusion

T_a is the input temperature

q_m is the metabolic heat in W/m^3

4.7.3. Usage of Data in the Simulation

The properties listed in the table are crucial for accurately modelling the interaction of EM waves with human head tissues. The density, specific heat, and thermal conductivity are used in the bioheat equation to determine the thermal response of the tissues when exposed to EM waves. The electrical conductivity, which varies with frequency, affects how the electromagnetic fields propagate through the tissues.

By incorporating these properties into the FDTD method and the bioheat equation, the simulation can more precisely predict the specific absorption rate (SAR) and temperature distribution within the tissues. This helps in assessing potential health risks associated with EM wave exposure from wireless communication devices.

Table 4.9: The basis data for the tissues [29]

Tissues	**Density**	**The specific heat**	**The thermal Conductivity**	**Frequency on MHz**	**Electrical conductivity**
Skin	1100	3500	0.50	900	0.87
				1800	1.18
Bone	1850	1300	0.30	900	0.14
				1800	0.28
Brain	1030	3500	0.60	900	1.15
				1800	1.48

4.7.4. Results

4.7.4.1. For the skin at 900 MHz

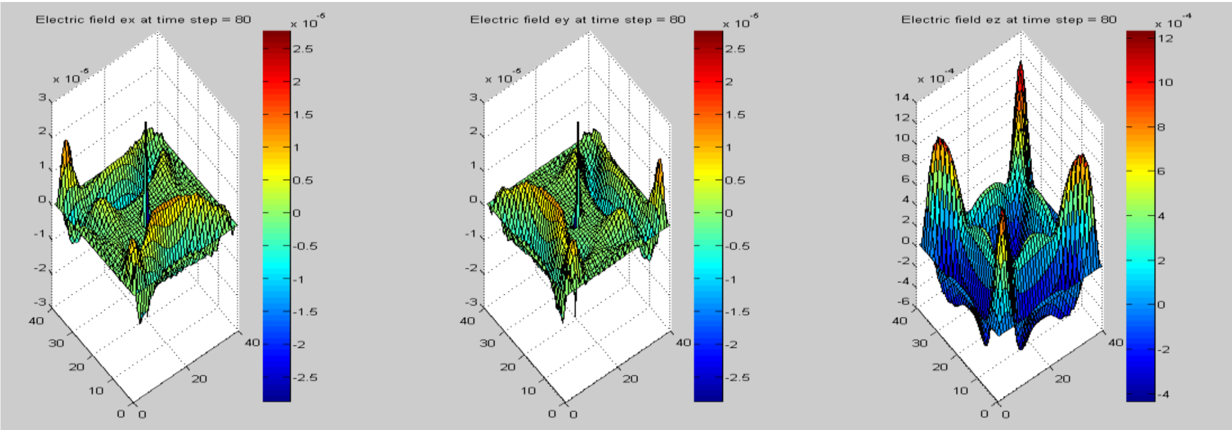

Figure 4.13: The electric fields distribution on 3D in the skin layer at the 900 MHz

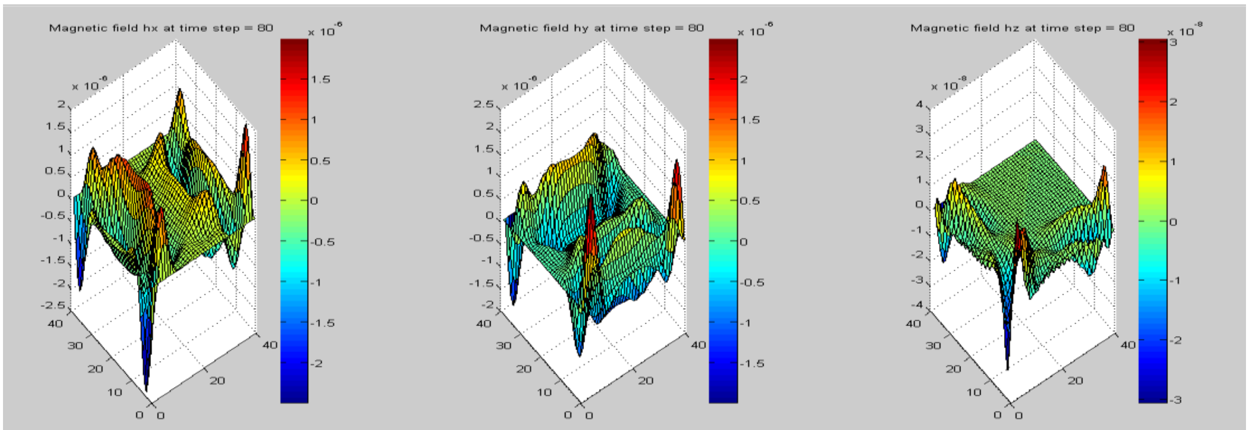

Figure 4.14: The magnetic fields distribution on 3D in the skin layer at the 900 MHz

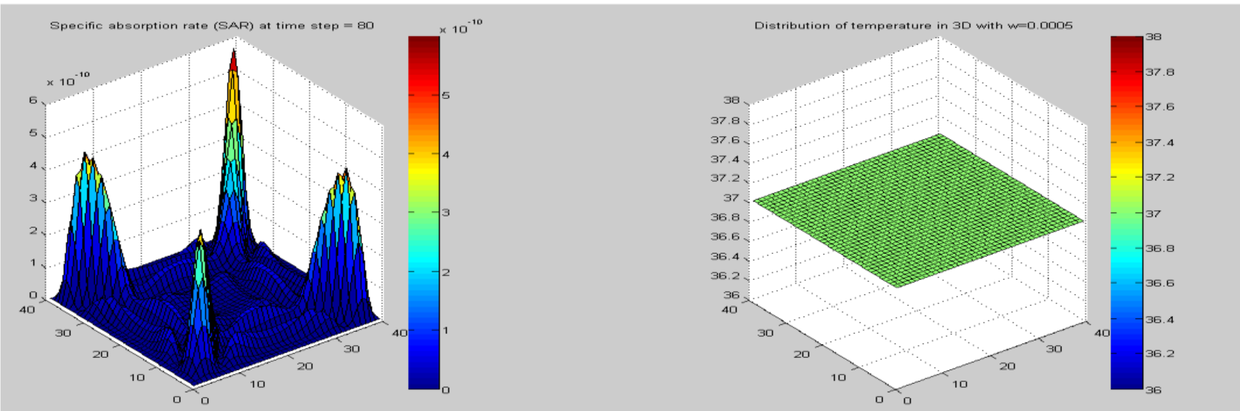

Figure 4.15: Distribution of the SAR and the temperature on 3D in the skin layer at 900 MHz

4.7.4.2. For the skin at 1800 MHz

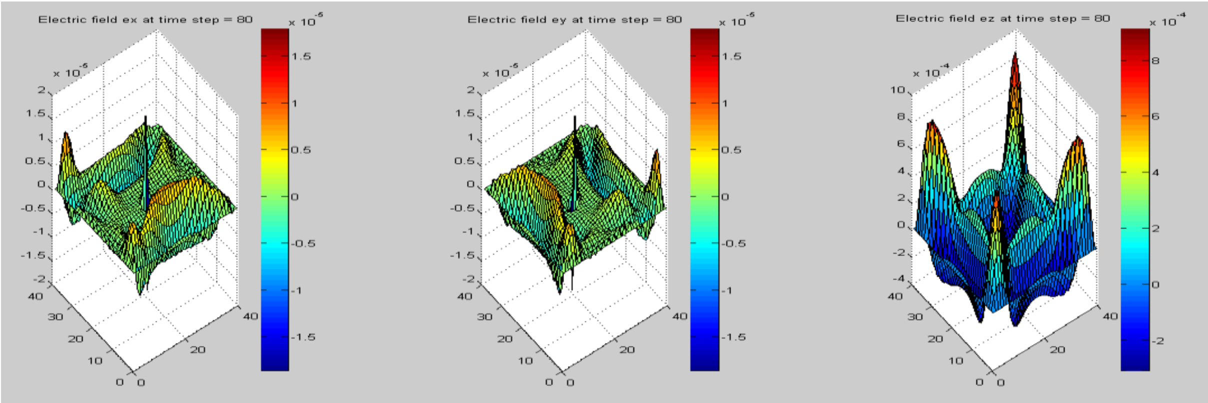

Figure 4.16: The electric fields distribution on 3D in the skin layer at the 1800 MHz

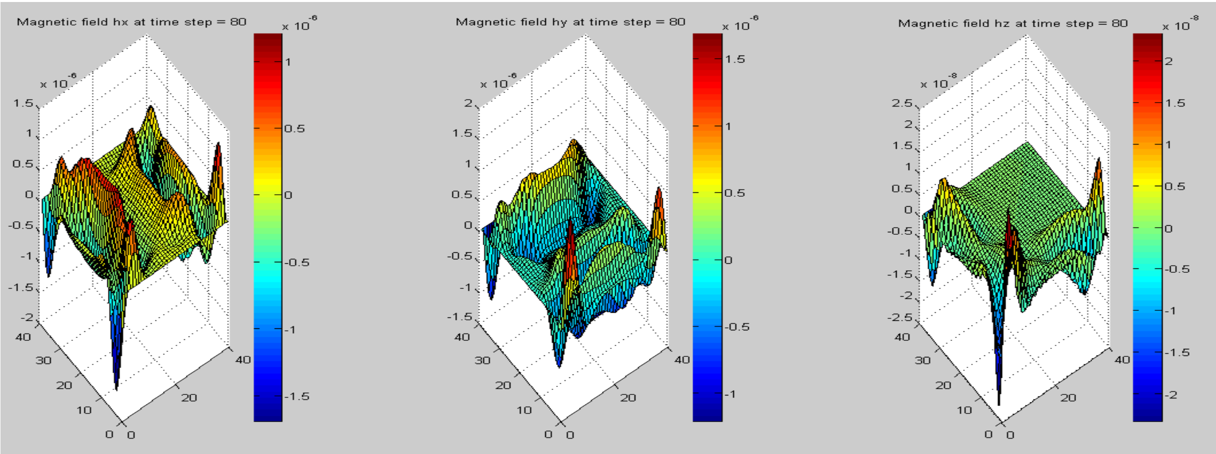

Figure 4.17: The magnetic fields distribution on 3D in the skin layer at the 1800 MHz

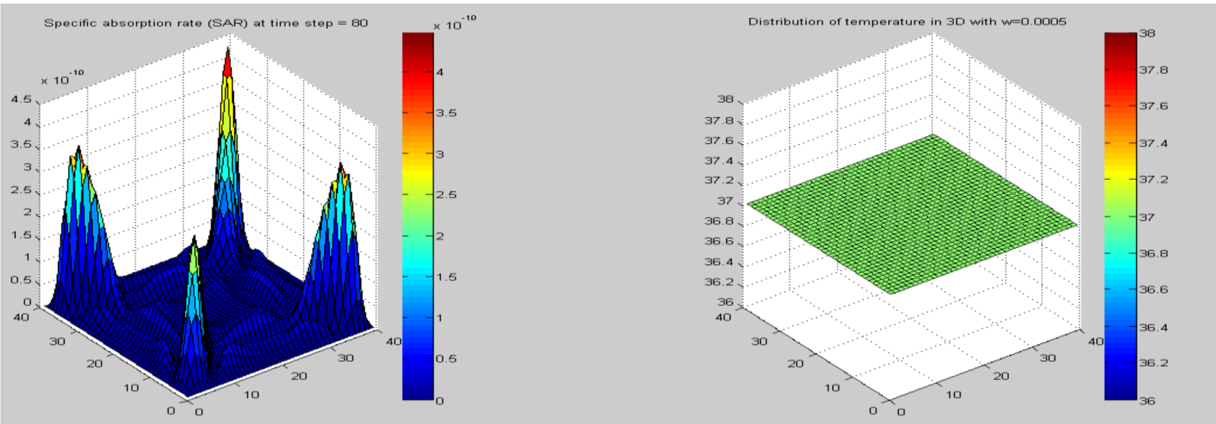

Figure 4.18: Distribution of the SAR and the temperature on 3D in the skin layer at 1800 MHz

4.7.4.3. For bone at 900 MHz

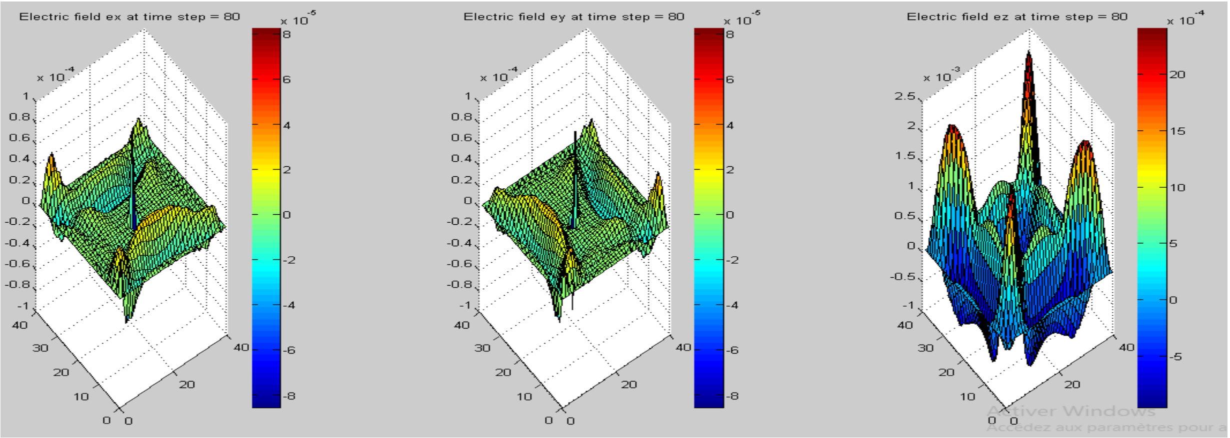

Figure 4.19: The electric field distribution in the bone at 900 MHz

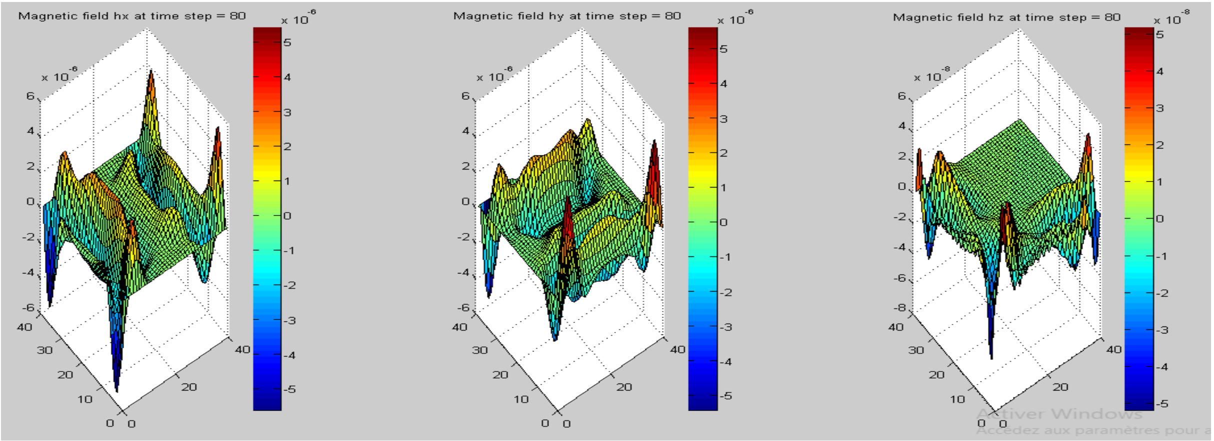

Figure 4.20: The magnetic fields distribution on 3D in the bone's layer at the 900 MHz

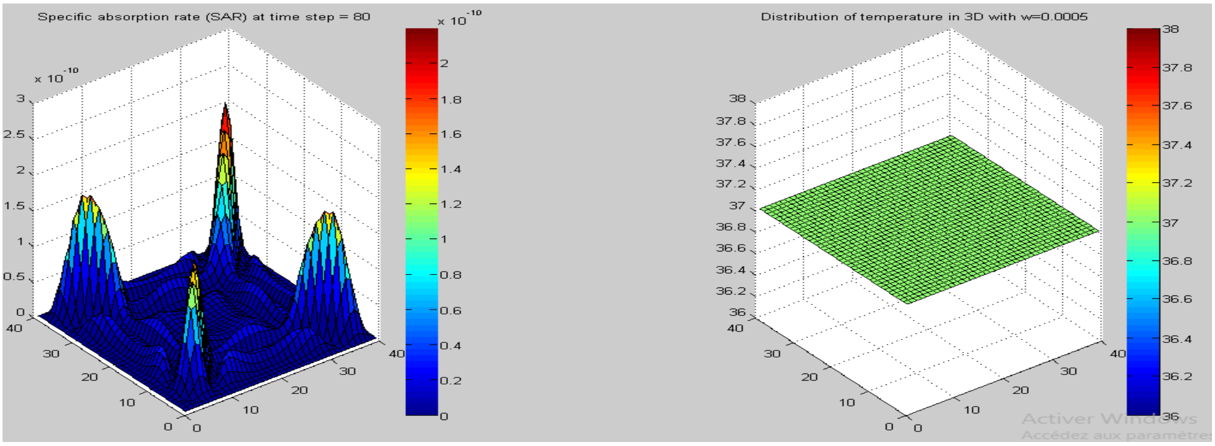

Figure 4.21: Distribution of the SAR and the temperature on 3D in the bone's layer at 900 MHz

4.7.4.4. For 1800 MHz

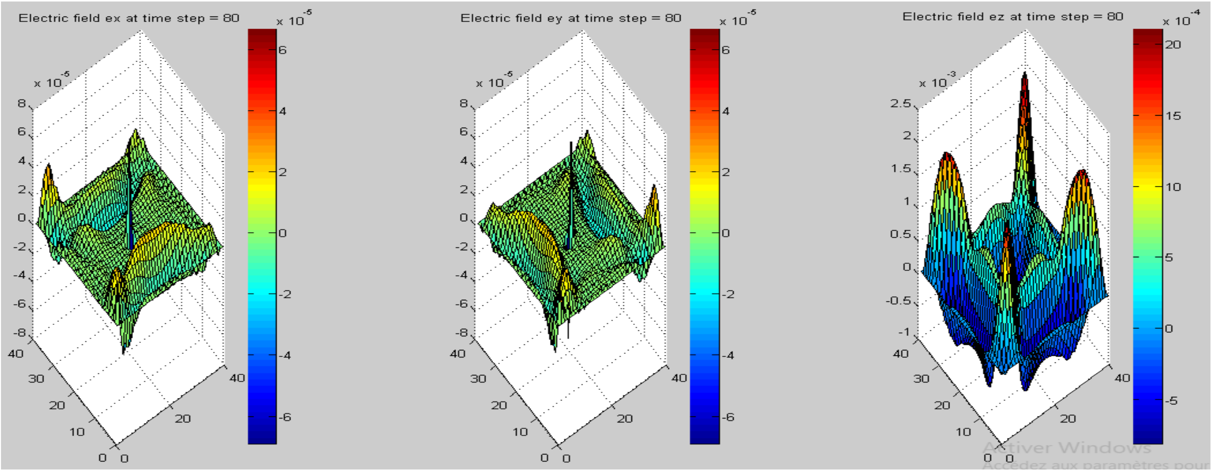

Figure 4.22: The electric field distribution in the bone at 1800 MHz

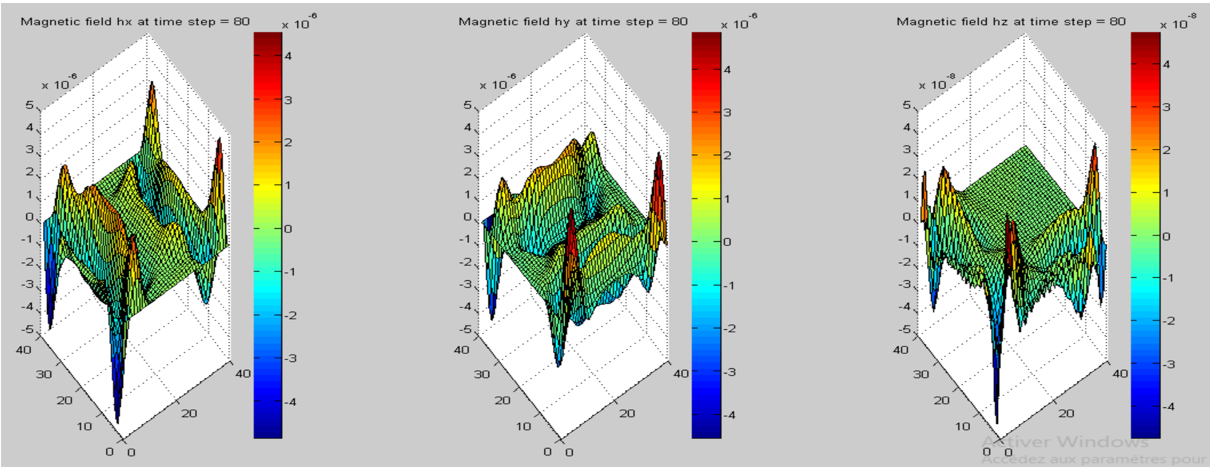

Figure 4.23: The magnetic fields distribution on 3D in the bone's layer at the 1800 MHz

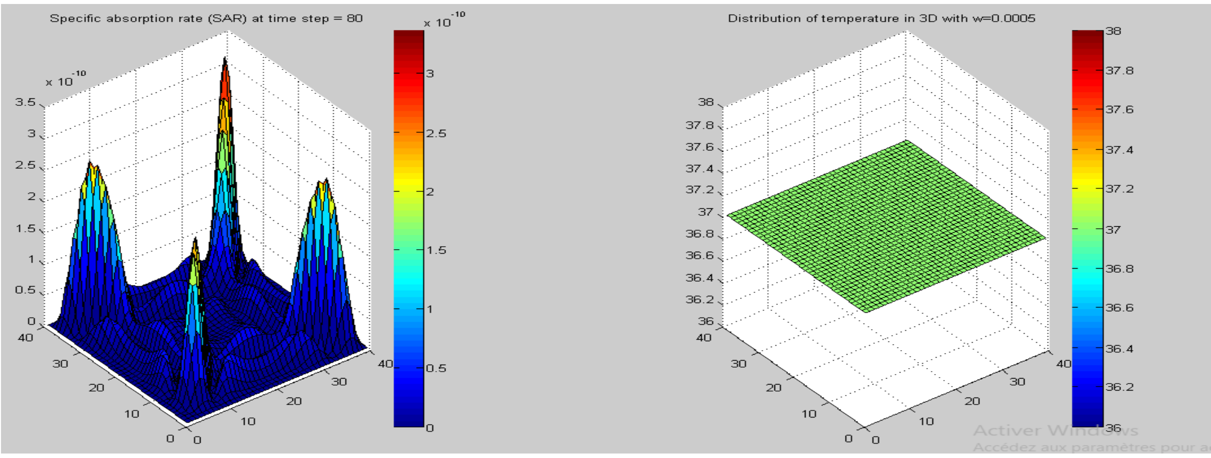

Figure 4.24: Distribution of the SAR and the temperature on 3D in the bone's layer at 1800 MHz

4.7.4.5. For the brain at 900 MHz

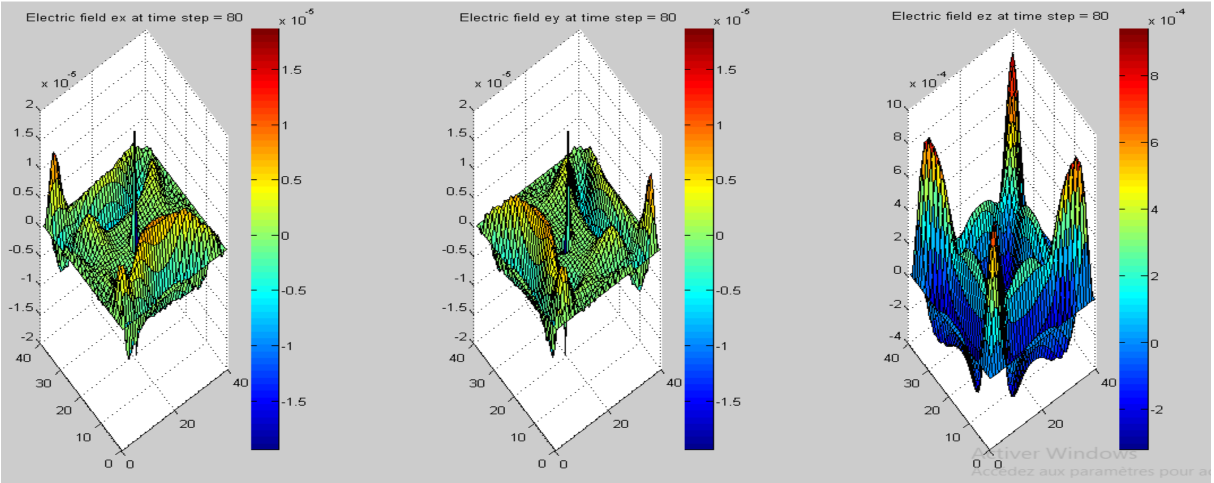

Figure 4.25: The electric field distribution in the brain at 900 MHz

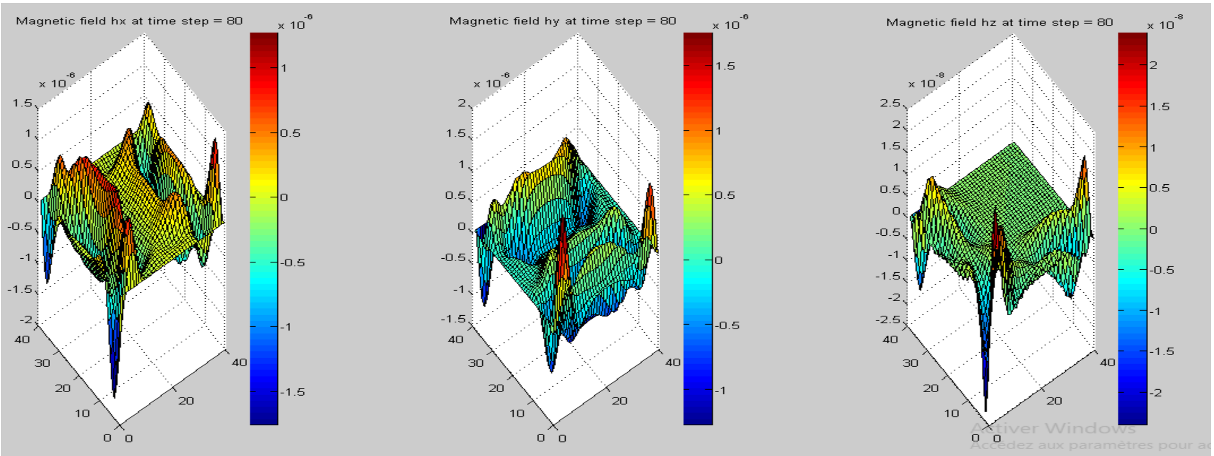

Figure 4.26: The magnetic fields distribution on 3D in the brain's layer at the 900 MHz

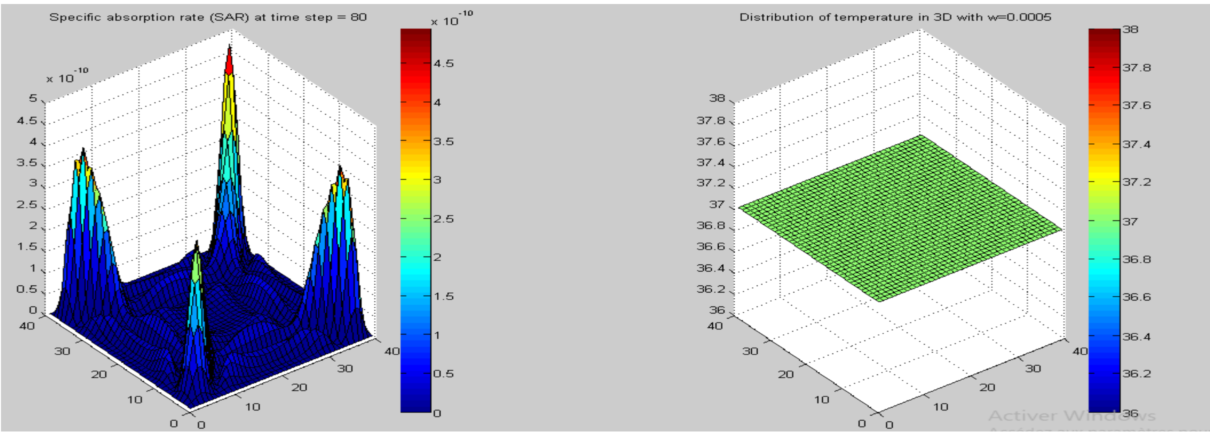

Figure 4.27: Distribution of the SAR and the temperature on 3D in the brain's layer at 900 MHz

4.7.4.6. For the brain at 1800 MHz

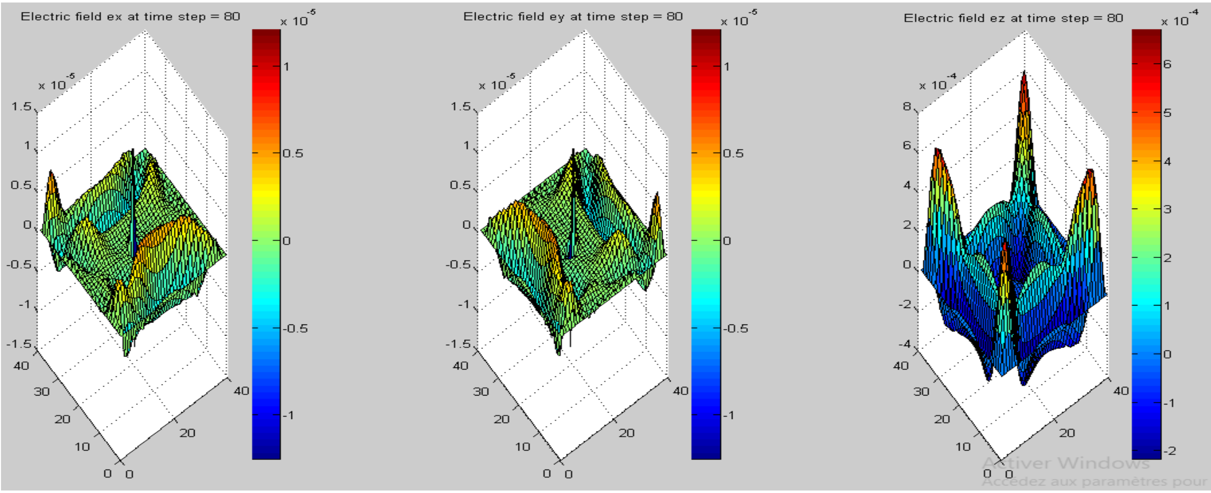

Figure 4.28: The electric field distribution in the brain at 1800 MHz

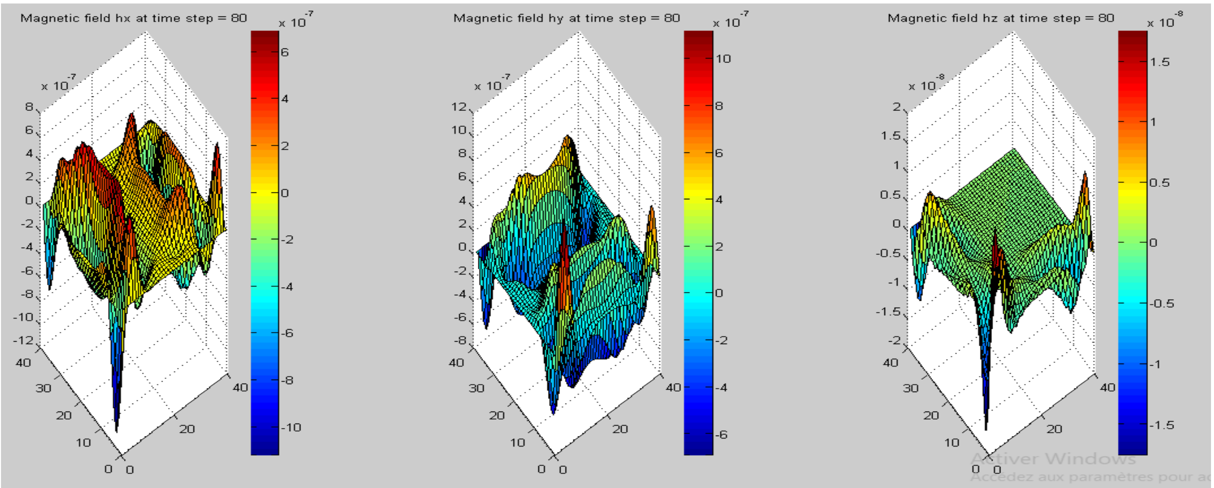

Figure 4.29: The magnetic fields distribution on 3D in the brain's layer at the 1800 MHz

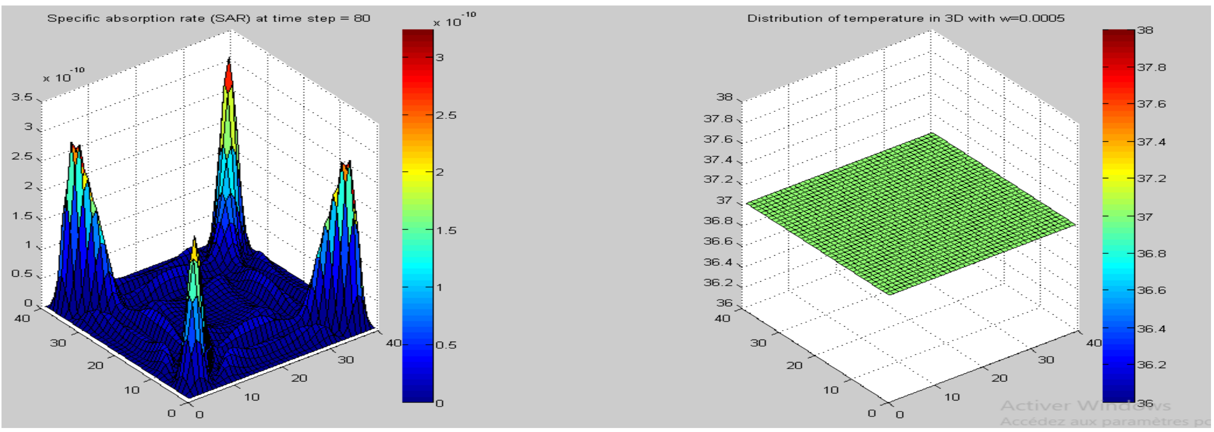

Figure 4.30: Distribution of the SAR and the temperature on 3D in the brain's layer at 1800 MHz

Table 4.10: Results for each layers at 900 MHz

Layers	ex peaks	ey peaks	ez peaks	hx peaks	hy peaks	hz peaks	SAR peaks
Skin	1.782e-05 2.775e-05	1.782e-05 2.775e-05	0.001075 0.001016 0.001232	1.086e-06 1.99e-06 1.07e-06 1.439e-06	1.93e-06 2.49e-06 1.05e-06 1.16e-06	1.646e-08 2.28e-08 1.859e-08	4.567e-10 4.08 e-10 4.56 e-10 5.99 e-10
Bone	4.537 e-05 9.58 e-06	4.537 e-05 9.58 e-06	0.002097 0.002082 0.002139 0.002317	4.116 e-06 5.42 e-06 2.9 e-06 3.48 e-06	5.44 e-6 5.332e-06	4.756 e-08 4.994 e-08	1.735 e-10 1.614 e-10 2.198 e-10 1.664 e-10
Brain	1.205e-05 6.543e-06 1.871e-05	1.205e-05 6.543e-06 1.871e-05	0.0008036 0.0008092 0.0007783 0.0009411	6.121 e-07 5.495 e-07 1.272 e-06 1.028 e-06	5.995e-07 1.602e-06 1.081e-06	1.185e-08 2.395e-08 1.616e-08	4.944e-10 3.964e-10 3.964e-10 3.355 e-10

Table 4.11: results for each layers at 1800 MHz

Layers	ex peaks	ey peaks	ez peaks	hx peaks	hy peaks	hz peaks	SAR peaks
Skin	1.153e-05 6.371e-06	7.19e-06 1.153e-05	0.00078 0.00091 0.00082 0.000106	4.83e-07 1.208e-06	1.53e-06 1.165e-06	1.739e-08 1.746e-08	3.609e-10 3.084e-10 3.609e-10 4.476e-10
Bone	3.811e-05 2.331e-05 6.67e-05	3.608e-05 2.42e-05 6.67e-05	0.00187 0.00179 0.00187 0.002109	2.377e-06 2.939e-06 4.544e-06 3.105e-06	4.66e-6 4.456e-06 2.442e-06 3.882e-06	2.51e-08 3.133e-08 2.754e-08	2.521e-10 2.447e-10 2.521e-10 3.367e-10
Brian	7.134e-05 1.209e-05	7.134e-05 1.209e-05	0.0006263 0.0006097 0.000524 0.0006716	6.296e-07 6.67e-07 4.133e-07	1.001e-06 6.583e-07	1.294e-08 1.755e-08	2.818e-10 2.406e-10 2.67e-10 3.241e-10

4.7.5. Observations from the Results

- **Field Distributions**

Electric Fields (e_x, e_y, e_z): Generally, higher magnitudes of electric fields were observed at 1800 MHz compared to 900 MHz across all tissues. This indicates that tissues absorb more electromagnetic energy at higher frequencies.

Magnetic Fields (h_x, h_y, h_z): Similar trends were observed for magnetic fields, with higher values at 1800 MHz. However, the absolute values of magnetic fields were generally lower compared to electric fields.

- **Specific Absorption Rate (SAR)**

SAR values were higher at 1800 MHz compared to 900 MHz for all tissues. This suggests that tissues absorb more energy per unit mass at higher frequencies, which can lead to higher thermal effects.

SAR peaks varied across tissues, with bone generally exhibiting higher SAR values compared to skin and brain at both frequencies.

- **Temperature Distribution**

The temperature distributions remained relatively stable around 37°C, which is within the normal physiological range. This indicates that the thermal effects, while present, are moderate under the simulated conditions.

- **Tissue-Specific Responses**

Skin Shows significant absorption of electromagnetic energy, particularly at higher frequencies, due to its proximity to external sources and its relatively high electrical conductivity.

Bone exhibits moderate absorption with SAR values indicating notable energy absorption; especially at 1800 MHz. This suggests potential localized heating effects in bone tissue.

Brain demonstrates relatively lower SAR values compared to skin and bone, indicating lower absorption of electromagnetic energy. However, the brain's sensitivity to temperature changes requires careful consideration despite lower SAR values.

- **Frequency Dependency**

The frequency dependency of electromagnetic wave interaction is evident from the varying SAR and field distributions. Higher frequencies lead to higher energy absorption and thus potentially greater thermal effects in tissues.

4.7.6. Conclusion

Frequency effects, higher frequencies generally resulted in higher electric and magnetic field intensities and SAR values across all tissues. Tissue variability, different tissues (skin, bone, and brain) exhibited varying absorption and thermal responses due to differences in electrical properties (conductivity) and physical characteristics (density, specific heat). Health implications, assessing SAR peaks is critical for understanding potential thermal effects and ensuring safety guidelines are met for electromagnetic exposure.

In conclusion, the FDTD simulations combined with the bioheat equation provide detailed insights into how electromagnetic waves interact with human tissues, contributing to the assessment of health risks associated with wireless communication devices. These findings are pivotal for advancing safety standards and guidelines in electromagnetic radiation exposure.

General conclusion

This study has provided a comprehensive evaluation of the interaction between electromagnetic waves and human body, focusing on the implications for wireless communication technologies. By analysing specific absorption rate (SAR) levels and the distribution of electric and magnetic fields at different frequencies and transmitted power levels, we have gained crucial insights into the potential health risks associated with electromagnetic radiation exposure. Our findings have indicated that higher frequencies, such as 1800 MHz and 2400 MHz, result in greater attenuation over distance and higher SAR values compared to lower frequencies like 900 MHz. This has increased energy absorption at higher frequencies can lead to more significant thermal effects within tissues, underscoring the importance of frequency selection in wireless communication systems. Through the application of the Finite-Difference Time-Domain (FDTD) method and the bioheat equation, we have demonstrated the utility of rigorous methods in simulating the complex interactions of electromagnetic waves with various tissue types, including skin, bone, and brain. These simulations have revealed that different tissues exhibit varying degrees of absorption and thermal response due to their distinct electrical and physical properties. The results have underscored the critical relationship between distance, frequency, and received power in communication systems. As distance increases, attenuation significantly impacts the received power, particularly at higher frequencies. This relationship highlights the necessity for careful consideration of frequency and power levels in the design and regulation of wireless communication technologies to ensure safety and effectiveness. Overall, this study has emphasized the importance of detailed modelling and simulation in understanding the health implications of electromagnetic wave exposure. By contributing valuable data and insights, this research supports the development of safer wireless communication technologies and informs the establishment of effective safety guidelines and regulatory standards. In summary, to avoiding the high absorption, consequently the high effect of electromagnetic waves on human health, we have to stay away as possible from any radiating sources such as BTS, relays, antennas and so on.

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ANNEXE

Matlab Codes

```
% define the human head Layers
% Number of layers
numLayers = 6;

% Layer names
layerNames = {'Skin', 'Fat', 'Bone', 'Dura', 'CSF', 'Brain'};

% Initialize arrays to store the input values
sigma = zeros(1, numLayers);
rho = zeros(1, numLayers);

% Number of electric field (E) values
numE = 5;

% Initialize an array to store E values
E_values = zeros(1, numE);

% Input the electric field (E) values
for j = 1:numE
E_values(j) = input(['Enter the electric field (E) value ' num2str(j) ' in (V/m):
']);
end

% Prompt user to enter values for each layer
for i = 1:numLayers
    fprintf('Enter properties for layer %d (%s):\n', i, layerNames{i});
    sigma(i) = input('  Conductivity (sigma) in (S/m): ');
    rho(i) = input('  Density (rho) in (Kg/m^3): ');
end

% Initialize a matrix to store SAR values for each layer and each E value
SAR_matrix = zeros(numLayers, numE);

% Calculate SAR for each layer and each E value
for j = 1:numE
    for i = 1:numLayers
        SAR_matrix(i, j) = (sigma(i) * (E_values(j)^2)) / rho(i);
    end
end

% Display the SAR values for each layer and each E value
for j = 1:numE
    fprintf('\nFor E = %.2f V/m:\n', E_values(j));
    for i = 1:numLayers
        fprintf('  SAR for layer %d (%s) is: %.4f W/kg\n', i, layerNames{i},
SAR_matrix(i, j));
    end
end

% Calculate and display the average SAR for each E value
for j = 1:numE
    avgSAR = mean(SAR_matrix(:, j));
```

```
    fprintf('The average SAR for the 6-layer head model with E = %.2f V/m is: %.4f W/kg\n', E_values(j), avgSAR);
end

% Plot the SAR values for each layer for each E value
figure;
hold on;
colors = lines(numE); % Use different colors for each E value
barWidth = 0.15; % Define bar width
for j = 1:numE
    bar((1:numLayers) - (numE/2 - j) * barWidth, SAR_matrix(:, j), barWidth, 'FaceColor', colors(j,:));
end
title('SAR Values for Each Layer');
xlabel('Layer');
ylabel('SAR (W/kg)');
legend(arrayfun(@(x) sprintf('E = %.2f V/m', x), E_values, 'UniformOutput', false));
xticks(1:numLayers);
xticklabels(layerNames);
grid on;
hold off;

% Plot SAR as a function of E for each layer
figure;
hold on;
for i = 1:numLayers
    plot(E_values, SAR_matrix(i, :), '-o', 'DisplayName', layerNames{i});
end
title('SAR as a Function of Electric Field (E)');
xlabel('Electric Field (E) in V/m');
ylabel('SAR (W/kg)');
legend('show');
grid on;
hold off;
```

Script 2 For the mobile phone

```
% Number of layers
numLayers = 6;
% Layer names
layerNames = {'Skin', 'Fat', 'Bone', 'Dura', 'CSF', 'Brain'};

% Initialize arrays to store the input values
sigma_GSM = zeros(1, numLayers);
sigma_LTE = zeros(1, numLayers);
rho = zeros(1, numLayers);

% Define mobile phone types and their associated electric field (E) values in V/m
phoneTypes = {'Xioami Note 4(GSM1800)', 'iPhone 6s(GSM1800)', 'Honor 9(LTE2400)', 'iPhone 6(LTE2400)'};
phoneEValues = [2.791, 0.75, 6.16, 0.72]; % Example E values for each phone type

% Number of electric field (E) values
numE = length(phoneEValues);

% Initialize an array to store E values
E_values = phoneEValues;
```

```
% Prompt user to enter conductivity values for each layer for GSM
fprintf('Enter properties for GSM (1800 MHz):\n');
for i = 1:numLayers
    fprintf('Enter properties for layer %d (%s):\n', i, layerNames{i});
    sigma_GSM(i) = input('  Conductivity (sigma) in (S/m) for GSM: ');
end

% Prompt user to enter conductivity values for each layer for LTE
fprintf('Enter properties for LTE (2400 MHz):\n');
for i = 1:numLayers
    fprintf('Enter properties for layer %d (%s):\n', i, layerNames{i});
    sigma_LTE(i) = input('  Conductivity (sigma) in (S/m) for LTE: ');
end

% Prompt user to enter density values for each layer
for i = 1:numLayers
    fprintf('Enter properties for layer %d (%s):\n', i, layerNames{i});
    rho(i) = input('  Density (rho) in (Kg/m^3): ');
end

% Validate the inputs
if any(sigma_GSM <= 0) || any(sigma_LTE <= 0) || any(rho <= 0)
    error('Conductivity and density values must be positive.');
end

% Initialize a matrix to store SAR values for each layer and each E value
SAR_matrix = zeros(numLayers, numE);

% Calculate SAR for each layer and each E value
for j = 1:numE
    for i = 1:numLayers
        if j <= 2  % First two phones are GSM
            SAR_matrix(i, j) = (sigma_GSM(i) * (E_values(j)^2)) / rho(i);
        else  % Last two phones are LTE
            SAR_matrix(i, j) = (sigma_LTE(i) * (E_values(j)^2)) / rho(i);
        end
    end
end

% Display the SAR values for each layer and each E value
for j = 1:numE
    fprintf('\nFor %s (E = %.2f V/m):\n', phoneTypes{j}, E_values(j));
    for i = 1:numLayers
        fprintf('  SAR for layer %d (%s) is: %.4f W/kg\n', i, layerNames{i},
SAR_matrix(i, j));
    end
end

% Calculate and display the average SAR for each E value
for j = 1:numE
    avgSAR = mean(SAR_matrix(:, j));
    fprintf('The average SAR for the 6-layer head model with %s (E = %.2f V/m) is:
%.4f W/kg\n', phoneTypes{j}, E_values(j), avgSAR);
end

% Plot the SAR values for each layer for each E value
figure;
hold on;
colors = lines(numE); % Use different colors for each E value
```

```
barWidth = 0.15; % Define bar width
for j = 1:numE
    bar((1:numLayers) - (numE/2 - j) * barWidth, SAR_matrix(:, j), barWidth,
'FaceColor', colors(j,:));
end
title('SAR Values for Each Layer');
xlabel('Layer');
ylabel('SAR (W/kg)');
legend(phoneTypes, 'Location', 'best');
xticks(1:numLayers);
xticklabels(layerNames);
grid on;
hold off;

% Plot SAR as a function of E for each layer
figure;
hold on;
for i = 1:numLayers
    plot(E_values, SAR_matrix(i, :), '-o', 'DisplayName', layerNames{i});
end
title('SAR as a Function of Electric Field (E)');
xlabel('Electric Field (E) in V/m');
ylabel('SAR (W/kg)');
legend('show', 'Location', 'best');
grid on;
hold off;
```

Script 3 for the Received power and the attenuation

```
% Speed of light (m/s)
c = 3e8;

% Input parameters
Pe = input('Enter the transmitted power (in watts): '); % Transmitted power
(W)
Ge = input('Enter the gain of the transmitting antenna: '); % Gain of the
transmitting antenna
Gr = input('Enter the gain of the receiving antenna: '); % Gain of the
receiving antenna
frequencies = input('Enter the frequencies (in MHz) as a vector [f1, f2,
f3]: '); % Frequencies (MHz)
d_min = input('Enter the minimum distance (in meters): '); % Minimum
distance (m)
d_max = input('Enter the maximum distance (in meters): '); % Maximum
distance (m)

% Create a vector of distances over the specified interval
distances = linspace(d_min, d_max, 1000);

% Initialize matrices to store results
attenuation_dB = zeros(length(frequencies), length(distances));
received_power = zeros(length(frequencies), length(distances));
received_power_dBm = zeros(length(frequencies), length(distances));

% Loop over each frequency to calculate the required values for the
distance range
for i = 1:length(frequencies)
    frequency = frequencies(i) * 1e6; % Convert MHz to Hz
```

```
    % Calculate the wavelength
    lambda = c / frequency;

    for j = 1:length(distances)
        d = distances(j);

        % Calculate the received power using Friis equation
        Pr = Pe * Ge * Gr * (lambda / (4 * pi * d))^2;

        % Calculate the link attenuation (ratio)
        alpha_l = (lambda / (4 * pi * d))^2;

        % Calculate the propagation attenuation (ratio)
        alpha_P = alpha_l;

        % Calculate the attenuation in dB
        attenuation_dB(i, j) = -10 * log10(alpha_l);

        % Store the received power
        received_power(i, j) = Pr;

        % Convert the received power to dBm
        received_power_dBm(i, j) = 10 * log10(Pr); % Convert W to mW and
then to dBm 10 * log10(Pr * 1e3)
    end
end

% Display calculated results at the given frequencies and distances
fprintf('Results:\n');
for i = 1:length(frequencies)
    fprintf('Frequency: %.2f MHz\n', frequencies(i));
    for j = 1:length(distances)
        if mod(j, 100) == 1 || j == length(distances) % Print every 100th
value and the last value
            fprintf('Distance: %.2f m, Attenuation: %.2f dB, Received
Power: %.6f W, Received Power: %.2f dB\n',distances(j), attenuation_dB(i,
j), received_power(i, j), received_power_dBm(i, j));
        end
    end
    fprintf('\n');
end

% Plot the attenuation in dB as a function of distance for each frequency
figure;
hold on;
colors = ['r', 'g', 'b']; % Colors for different frequencies
for i = 1:length(frequencies)
    plot(distances, attenuation_dB(i, :), 'LineWidth', 2, 'Color',
colors(i), 'DisplayName', sprintf('Frequency = %.2f MHz', frequencies(i)));
end
title('Attenuation in dB vs Distance');
xlabel('Distance (m)');
ylabel('Attenuation (dB)');
legend show;
grid on;
hold off;

% Plot the received power in Watts as a function of distance for each
frequency
figure;
hold on;
```

```
for i = 1:length(frequencies)
    plot(distances, received_power(i, :), 'LineWidth', 2, 'Color',
colors(i), 'DisplayName', sprintf('Frequency = %.2f MHz', frequencies(i)));
end
title('Received Power vs Distance (Watts)');
xlabel('Distance (m)');
ylabel('Received Power (W)');
legend show;
grid on;
hold off;

% Plot the received power in dBm as a function of distance for each
frequency
figure;
hold on;
for i = 1:length(frequencies)
    plot(distances, received_power_dBm(i, :), 'LineWidth', 2, 'Color',
colors(i), 'DisplayName', sprintf('Frequency = %.2f MHz', frequencies(i)));
end
title('Received Power vs Distance (dB)');
xlabel('Distance (m)');
ylabel('Received Power (dB)');
legend show;
grid on;
hold off;
```

SCRIPT 4 FOR THE FDTD

```
%3D FDTD bioheat equation
format long g
clear all;
close all;
IE=40;
JE=40;
KE=40;
cc=2.99792458e8; %Light speed
mu_0=4.0*pi*1.0e-7; %permeability of free space
eps_0=1.0/(cc*cc*mu_0); %permittivity of free space
G=ones(IE,JE,KE)*1.48; %conductivity of the tissue[Skin_at
900:0.87,1800=1.18,2400=1.44__Fat_at900=0.051,1800=0;078,2400=0.102__Brain9
00=0.77,1800=1.15,2400=1.48]
Roe=1030*ones(IE,JE,KE); %masse volumique or the density [1100,920,1030]
ic=floor(IE/2);
jc=floor(JE/2);
kc=floor(KE/2);
ddx=0.0002; %pas de discrétisation spatial
ddy=0.0002;
ddz=0.0002;
dt=ddx/(2.0*cc); %pas de temps
ex=zeros(IE,JE,KE); % electrical field ex
ey=zeros(IE,JE,KE); %electrical field ey
ez=zeros(IE,JE,KE); %electrical field ez
dx=zeros(IE,JE,KE); %electric induction dx
dy=zeros(IE,JE,KE); %electric induction dy
dz=zeros(IE,JE,KE); %induction electrique dz
hx=zeros(IE,JE,KE); % magnetic field hx
hy=zeros(IE,JE,KE); % magnetic field hy
hz=zeros(IE,JE,KE); % magnetic field hz
sar=zeros(IE,JE,KE); % initial specific absorption rate
Er=ones(IE,JE,KE); % relative permittivity
gx=ones(IE,JE,KE);
```

```
gy=ones(IE,JE,KE);
gz=ones(IE,JE,KE);
%--------------------specify the Dipole------------------------------------
for k=11:30
gz(:,:,k)=0.0;
end
gaz(ic,jc,kc)=0.0;

gaz=ones(IE,JE,KE);

%---------------------Time instance specification-------------------------
t0=20.0;
spread=6.0;
T=0;
nsteps=80;
for n=1:1:nsteps
T=T+1;
%************************************************************************
% Updating coefficients
%************************************************************************
ca(:,:,:,1)=(1.0-(dt*G)./(2.0*eps_0*Er))./(1.0+(dt*G)./(2.0*eps_0*Er));
cb(:,:,:,1)=(dt/eps_0/Er/ddx)./(1.0+(dt*G)./(2.0*eps_0*Er));
da = 1.0; %((cc*dt)/(dx))^2;
db(:,:,:,1) = (dt/ mu_0/ ddx)./(1.0+(dt*G)./(2.0*eps_0*Er));
%----------------------Calculate the Dx field-----------------------------
for k=2:KE
for j=2:JE
for i=2:IE
dx(i,j,k)=ca(i,j,k).*dx(i,j,k)+cb(i,j,k).*(hz(i,j,k)-hz(i,j-1,k)-
hy(i,j,k)+hy(i,j,k-1));
end
end
end
%------------------------Calculate of the Dy field------------------------
for k=2:KE
for j=2:JE
for i=2:IE

dy(i,j,k)= ca(i,j,k).*dy(i,j,k)+cb(i,j,k).*(hx(i,j,k)-hx(i,j,k-1)-
hz(i,j,k)+hz(i-1,j,k));

end
end
end
%---------------------Calculate the Dz field------------------------------
for k=2:KE
for j=2:JE
for i=2:IE

dz(i,j,k)=ca(i,j,k).*dz(i,j,k)+ cb(i,j,k).*(hy(i,j,k)-hy(i-1,j,k)-
hx(i,j,k)+hx(i,j-1,k));

end
end
end
%----------------------source---------------------------------------------
pulse=exp(-0.5*((t0-T)/spread)^2.0);
dz(ic,jc,kc)=pulse;
%--------------Calculate the E from D field-------------------------------
for k=1:KE-1
for j=1:JE-1
```

```
for i=1:IE-1
ex(i,j,k)=dx(i,j,k)/Er(i,j,k);
ey(i,j,k)=dy(i,j,k)/Er(i,j,k);
ez(i,j,k)=dz(i,j,k)/Er(i,j,k);
end
end
end
%-----------------------calculate SAR -----------
sar1=abs(ex(:,:,:)).^2+abs(ey(:,:,:)).^2+abs(ez(:,:,:)).^2;
sar= G.*sar1./(2*Roe);
%---------------------- profondeur de pénetration--------------------------
---
freq1=2e6;
w=2*pi*freq1;
prof=sqrt(2/w*mu_0*G);

%-----------------Calculate the Hx field-----------------------------------
for k=1:KE-1
for j=1:JE-1
for i=1:IE
hx(i,j,k)=da.*hx(i,j,k)+db(i,j,k).*(ey(i,j,k+1)-ey(i,j,k)-
ez(i,j+1,k)+ez(i,j,k));
end
end
end
%---------------Calculate the Hy field-------------------------------------
for k=1:KE-1
for j=1:JE
for i=1:IE-1
hy(i,j,k)=da.*hy(i,j,k)+db(i,j,k).*(ez(i+1,j,k)-ez(i,j,k)-
ex(i,j,k+1)+ex(i,j,k));
end
end
end
%-----------------Calculate the Hz field-----------------------------------
for k=1:KE
for j=1:JE-1
for i=1:IE-1
hz(i,j,k)=da.*hz(i,j,k)+db(i,j,k).*(ex(i,j+1,k)-ex(i,j,k)-
ey(i+1,j,k)+ey(i,j,k));
end
end
end
end
%***********************************************************************
% Grid parameters
%***********************************************************************
sar1=abs(ex(:,:,:)).^2+abs(ey(:,:,:)).^2+abs(ez(:,:,:)).^2;
sar= G.*sar1./(2*Roe);
tcon =3;
ib = IE;
jb = JE;
kb = KE;

tt=ones(ib,jb,kb,tcon)*37; %température initiale
G=ones(ib,jb,kb)*1.48; %conductivité de tissus
Roe=ones(ib,jb,kb)*1030;%1057; %masse volumique de tissus
%1057 = masse volumique de sang
%3600= chaleur spécific de sang
for perf1=0:0.01
sph=ones(ib,jb,kb)*3500;%1000; %chaleur spécific de tissus
```

```
perf=ones(ib,jb,kb)*0; %taux de perfusion de sang
Qmet=ones(ib,jb,kb)*980; %énergie de chaleur métabolique
therm=ones(ib,jb,kb)*0.60; %conductivity thermique
tt1=ones(ib,jb,kb)*0;
tt2=ones(ib,jb,kb)*0;
tt3=ones(ib,jb,kb)*0;
Qem= sar.*Roe; % l'énergie électromagnétique de processus

%******************************************************************
%Update temperature
%************************************************************************
ncur = 2;
npr1 = 1;
nmax=100;
dtt=0.25;
for n=1:nmax
%************************************************************************
% Update time container index
%***********************************************************************
npr2 = npr1;
npr1 = ncur;
ncur = mod(ncur+1,3);
if ncur == 0
ncur =3;
else
ncur = ncur;


tt1(2:IE-1,:,:)=(therm(3:IE,:,:).*tt(3:IE,:,:,npr1)-
therm(3:IE,:,:).*tt(1:IE-2,:,:,npr1)-therm(1:IE-
2,:,:).*tt(3:IE,:,:,npr1)+therm(1:IE-2,:,:).*tt(1:IE-2,:,:,npr1))/4
+therm(2:IE-1,:,:).*(tt(3:IE,:,:,npr1)-2*tt(2:IE-1,:,:,npr1)+tt(1:IE-
2,:,:,npr1));
tt1=tt1/ddx/ddx;

tt2(:,2:JE-1,:)=(therm(:,3:JE,:).*tt(:,3:JE,:,npr1)-
therm(:,3:JE,:).*tt(:,1:JE-2,:,npr1)-therm(:,1:JE-
2,:).*tt(:,3:JE,:,npr1)+therm(:,1:JE-2,:).*tt(:,1:JE-2,:,npr1))/4
+therm(:,2:JE-1,:).*(tt(:,3:JE,:,npr1)-2*tt(:,2:JE-1,:,npr1)+tt(:,1:JE-
2,:,npr1));
tt2=tt2/ddy/ddy;

tt3(:,:,2:KE-1)=(therm(:,:,3:KE).*tt(:,:,3:KE,npr1)-
therm(:,:,3:KE).*tt(:,:,1:KE-2,npr1)-therm(:,:,1:KE-
2).*tt(:,:,3:KE,npr1)+therm(:,:,1:KE-2).*tt(:,:,1:KE-2,npr1))/4
+therm(:,:,2:KE-1).*(tt(:,:,3:KE,npr1)-2*tt(:,:,2:KE-1,npr1)+tt(:,:,1:KE-
2,npr1));
tt3=tt3/ddz/ddz;

tt(:,:,:,ncur) = tt(:,:,:,npr1)+ dtt*(tt1+tt2+tt3-(4180*1060*perf.*(37-
tt(:,:,:,npr1))/6000)+Qmet+Qem)./Roe./sph;

end;
end;
tmax=nmax*dtt/60;
ee=tt(:,:,:,ncur);
[ix1,iy1,iz1]=size(ee);
i=1:ix1;
x1=(i-1)*ddx;
i=1:iy1;
y1=(i-1)*ddy;
```

```
i=1:iz1;
z1=(i-1)*ddz;
iz2=round(iz1/6)+1;
inx=ix1*iy1*iz1;
figure(1);
for isub=1:iz1;
subplot(iz2,6,isub);
ees1=ee(:,:,isub);
pcolor(x1,y1,ees1');
colorbar;
shading flat;
axis off;
end;
% %----------------graphe de distribution--------------------------------
% figure(2);
% timestep=int2str(T);
% surf(ex(1:IE,1:JE,kc));
% title(['champ magnétique hx at time step = ',timestep]);
% colorbar;
% pause(0.001)
% figure(3);
% timestep=int2str(T);
% surf(ey(1:IE,1:JE,kc));
% title(['champ magnétique hy at time step = ',timestep]);
% colorbar;
% pause(0.001)
% figure(4);
% timestep=int2str(T);
% surf(ez(1:IE,1:JE,kc));
% title(['Electric field ex at time step = ',timestep]);
% colorbar;
% pause(0.001)
% figure(5);
% timestep=int2str(T);
% surf(sar(1:IE,1:JE,kc));
% title(['specific absorpation rate (SAR) at time step = ',timestep]);
% colorbar;
% pause(0.001)
% figure(6);
% timestep=int2str(T);
% surf(ee(1:IE,1:JE,kc));
% title(['distribution of the tempurature on 3D avec w=0.0005 ']);
% colorbar;
% pause(0.001)


% %%part2graphic of electric field
% %----------------graphe de distribution--------------------------------
% figure(7);
% timestep=int2str(T);
% surf(hx(1:IE,1:JE,kc));
% title(['magnetic field hx at time step = ',timestep]);
% colorbar;
% pause(0.001)
% figure(8);
% timestep=int2str(T);
% surf(hy(1:IE,1:JE,kc));
% title(['magnetic field hy at time step = ',timestep]);
% colorbar;
% pause(0.001)
% figure(9);
```

```
% timestep=int2str(T);
% surf(hz(1:IE,1:JE,kc));
% title(['champ magnétique hz at time step = ',timestep]);
% colorbar;
% pause(0.001)

%%PART3 OF THE DISPLAY

figure;
timestep = int2str(T);

subplot(1, 3, 1);
surf(ex(1:IE, 1:JE, kc));
title(['Electric field ex at time step = ', timestep]);
colorbar;

subplot(1, 3, 2);
surf(ey(1:IE, 1:JE, kc));
title(['Electric field ey at time step = ', timestep]);
colorbar;

subplot(1, 3, 3);
surf(ez(1:IE, 1:JE, kc));
title(['Electric field ez at time step = ', timestep]);
colorbar;

pause(0.001);


figure;
timestep = int2str(T);

subplot(1, 3, 1);
surf(hx(1:IE, 1:JE, kc));  % Assuming hx, hy, hz are the magnetic field
components
title(['Magnetic field hx at time step = ', timestep]);
colorbar;

subplot(1, 3, 2);
surf(hy(1:IE, 1:JE, kc));
title(['Magnetic field hy at time step = ', timestep]);
colorbar;

subplot(1, 3, 3);
surf(hz(1:IE, 1:JE, kc));
title(['Magnetic field hz at time step = ', timestep]);
colorbar;

pause(0.001);


figure;
timestep = int2str(T);

subplot(1, 2, 1);
surf(sar(1:IE, 1:JE, kc));
title(['Specific absorption rate (SAR) at time step = ', timestep]);
colorbar;

subplot(1, 2, 2);
surf(ee(1:IE, 1:JE, kc));
```

```
title(['Distribution of temperature in 3D with w=0.0005 ']);
colorbar;

pause(0.001);

hold on

% Electric Field Components in One Figure
figure;
timestep = int2str(T);

subplot(1, 3, 1);
surf(ex(1:IE, 1:JE, kc));
title(['Electric field ex at time step = ', timestep]);
colorbar;

subplot(1, 3, 2);
surf(ey(1:IE, 1:JE, kc));
title(['Electric field ey at time step = ', timestep]);
colorbar;

subplot(1, 3, 3);
surf(ez(1:IE, 1:JE, kc));
title(['Electric field ez at time step = ', timestep]);
colorbar;

pause(0.001);

% Magnetic Field Components in One Figure
figure;
timestep = int2str(T);

subplot(1, 3, 1);
surf(hx(1:IE, 1:JE, kc));  % Assuming hx, hy, hz are the magnetic field
components
title(['Magnetic field hx at time step = ', timestep]);
colorbar;

subplot(1, 3, 2);
surf(hy(1:IE, 1:JE, kc));
title(['Magnetic field hy at time step = ', timestep]);
colorbar;

subplot(1, 3, 3);
surf(hz(1:IE, 1:JE, kc));
title(['Magnetic field hz at time step = ', timestep]);
colorbar;

pause(0.001);

% SAR and Temperature Distribution in One Figure
figure;
timestep = int2str(T);

subplot(1, 2, 1);
surf(sar(1:IE, 1:JE, kc));
title(['Specific absorption rate (SAR) at time step = ', timestep]);
colorbar;

subplot(1, 2, 2);
surf(ee(1:IE, 1:JE, kc));
```

```
title(['Distribution of temperature in 3D with w=0.0005 ']);
colorbar;

pause(0.001);

hold off
end
```