ANALYSIS OF MOBILE PHONE RADIATION EFFECT ON HUMAN BODY USING SPECIFIC ABSORPTION RATE

SAGAR MAHMUD

MASTER OF SCIENCE

NOAKHALI SCIENCE AND TECHNOLOGY UNIVERSITY

ANALYSIS OF MOBILE PHONE RADIATION EFFECT ON HUMAN BODY USING SPECIFIC ABSORPTION RATE

SAGAR MAHMUD

This thesis is submitted in partially fulfillment of the
requirements for the award of the degree of
Master of Science in Information and Communication
Engineering

Department of Information and Communication Engineering
NOAKHALI SCIENCE AND TECHNOLOGY
UNIVERSITY

MARCH 2021

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and, in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science (Engineering) in Department of Information and Communication Engineering of Noakhali Science and Technology University.

____

Name of Supervisor: DR. MD. ASHIKUR RAHMAN KHAN

Position: PROFESSOR & CHAIRMAN

Date:

____

Name of Co-Supervisor: ZAYED-US-SALEHIN

Position: ASSISTANT PROFESSOR

Date:

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations, references and summaries which have been duly acknowledged. This thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Sagar Mahmud

Roll: ASH1811MSc120M

Date:

ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor Professor Dr. Md. Ashikur Rahman Khan for his germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct, his strong conviction for science, and his belief that a MSc program is only a start of a life-long learning experience. I appreciate his consistent support from the first day I applied to graduate program to these concluding moments. I am truly grateful for his progressive vision about my training in science, his tolerance of my native mistakes, and his commitment to my future carrier. I also would like to express very special thanks to my co-supervisor Zayed-Us-Salehin for his suggestions and co-operations throughout the study. I also sincerely thanks for the time spent proofreading and correcting my many mistakes.

My sincere thanks go to all my lab mates, members of the staff of the Information and Communication Engineering Department, NSTU, who helped me in many ways and made my stay at NSTU pleasant and unforgettable.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. Special thanks should be given to my committee members. I would like to acknowledge their comments and suggestions which were crucial for the successful completion of this study.

ABSTRACT

The use of mobile phones is rising everyday both in civic and rustic areas in Bangladesh. Every mobile phone disperses electromagnetic energy. This radiation or electromagnetic wave can penetrate into the human body. Specific absorption rate and change in temperature are the vital parameter to find the dominant effects on the human body. Many researchers have done a lot of work on the effects of radiation for his or her country. But in Bangladesh, no visible work has been done yet. The importance of the health hazards due to radiation from the mobile phone has not been understood among the common people. Because it cannot be seen, felt or smelt and it is very hard to realize the evil part. Importance of mobile phone cannot be ignored because it's helps to keep in touch with family, friends and others to perform various tasks. This paper explores the radiation impact of mobile phones. Mathematical equations are used to evaluate the specific absorption rate and change in temperature at skin, fat, bone, brain, eye, muscle tissues at the frequency of 800MHz, 900 MHz, 1800 MHz, 2100 MHz, 2.5GHz, 2.6GHz, 3.4GHz, 3.5GHz, and 3.6GHz respectively. The calculations are performed at different distances and exposure times of mobile phone. A simple radio frequency detection circuit has been designed to find the radiated power of different frequency. The highest specific absorption rate is calculated for skin, brain, eye tissue. Child tissue absorption rate is higher than the adult. When the radiated power of mobile phone is high the specific absorption rate for different tissue crosses the safety limit. This paper also recommends the ways to diminish the effects of SAR. It is suggested that these methods will decrease the health risks. This work will be very helpful to understand the bad effect of using mobile phones and the way of reducing this effect.

TABLE OF CONTENTS

Contents **Page No**

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Symbol	Meaning
σ	Tissue conductivity
ρ	Human mass density
E	Electric field strength
S	Power density
η	Impedance
η_0	Free space impedance
μ_r	Relative permeability
d	Diameter of the imaginary sphere
S	Power density on the surface of the sphere
ε_r	Relative permittivity
μ_0	Free-space permeability
f	Frequency
l	Head-antenna separation distance
δ	Penetration depth
σ	Conductivity of the medium
T	Temperature
t	Exposure of time
C	Heat capacity
P	Total power at the source

LIST OF ABBREVIATIONS

1G	First generation
2G	Second generation
3G	Third generation
4G	Fourth generation
5G	Fifth generation
BS	Base station
CAD	Computer aided design
CDMA	Code division multiple access
EM	Electromagnetic
EME	Electromagnetic energy
EDGE	Enhanced data rates for GSM evolution
FCC	Federal communications commission
FDMA	Frequency division multiple access
FDTD	Finite difference time domain
FEM	Finite element method
GSM	Global system for mobile communications
HSPA	High speed packet access
HD	High definition
IC	Integrated circuit
IP	Internet protocol
ITU	International telecommunication union

LCD	Liquid crystal display
LED	Light emitting diode
LTE	Long term evolution
MIMO	Multiple input and multiple output
MSC	Mobile switching center
OFDM	Orthogonal frequency division multiplexing
PCB	Printed circuit board
PIFA	Planar inverted F antenna
RF	Radio frequency
SAR	Specific absorption rate
TDMA	Time division multiple access
UMTS	Universal mobile telecommunication system
WCDMA	Wideband code division multiple access,
WiMAX	Worldwide interoperability for microwave access
WWWW	Worldwide wireless web

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Mobile phone is the integral part of recent communications and are fast becoming a social lifestyle. The main source of electromagnetic energy (EME) is mobile phone and Base station (BS) transmitter antenna. The emitted electromagnetic energy is more powerful than the base stations as this usually held near to the head while being used. Mobile phone uses electromagnetic waves through radio frequency and microwave signals which is provided by mobile phone operators. It provides the facility to the subscriber wireless telecommunication system for better communication. When a man makes a call, the signal is transmitted from mobile phones to the base station. Base station assigns the accessible radio frequency channel. This assigned channel transmits the information to the base station. This voice signal also transmits to the mobile switching center (MSC). The switching center then transmits the voice call to the destination. These voice calls then conveyed back and forth during the call. It is assumed that the mobile phone radiation is harmful for the human biological function. Specific absorption rate and temperature changes of tissue are the essential parameters for find mobile phone radiation effect on human body. The Specific Absorption Rate is a process of detailed analysis and considered as one of the pioneering areas of research in exposure studies. The frequencies of operation and the modulation signal used for mobile communication system is showed at Table 1.1. This paper calculated the specific absorption rate for different frequencies and discuss the possible health hazards.

Table 1.1: Frequency used by different mobile phone networks

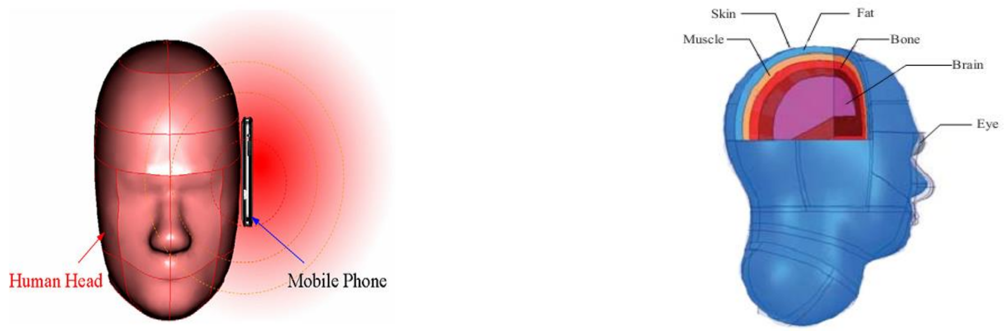
Generation	Frequency	Technology	Features
1G	800 MHz	FDMA	Based on analog system, channel bandwidth 30 kHz, data transmission up to 2.4 Kbps
2G	900, 1800 MHz	TDMA, CDMA, GSM	Based on digital technology, channel bandwidth 200 kHz (voice transmission). Allows multiple users on a single channel, data transmission up to 14– 64 Kbps.
3G	850, 900, 1700, 1900, 2100 MHz	CDMA2000 GPRS, EDGE UMTS, WCDMA, HSPA	Based on WCDMA, channel bandwidth 1.25 MHz (voice transmission). Provides high internet browsing speed, video streaming, video calling, data transmission 125 kbps to 2 Mbps.
4G	700, 850, 900, 1800, 1900, 2100, 2300, 2500, 2600 MHz	WiMAX, LTE, OFDM	Enhanced 3G, high-speed and IP-based networks, supports HD streaming, HD phones, data transmission up to 400 Mbps
5G	3-100 GHz	CDMA, WWWW	mmWave frequency, IP-based networks (internet of things), data transmission up to 1000 Mbps (gigabit speed)

1.2 THE SCENARIO OF HUMAN BODY AND MOBILE PHONE RADIATION

Mobile phone has different type of functional part. The radiated power from mobile phone is absorb by the human tissue. So, the tissue temperature is increased by this radiation.

1.2.1 Human Body

Human body has different types of components. The main component of human head is skin, fat, bone, brain muscle and eye. Human head tissue and exposed to mobile phone radiation is shown at Figure 1.1. These tissues have different dielectric and thermal properties. Exposure to electromagnetic radiation from high-power transmitters produces a perceptible increase in tissue temperature and organs. So, it has an adverse effect on human body. Therefore, studying the thermal effects on the human heads induced by the radiation of phones can provide guidelines for their design, manufacture, and usage, thus avoid or reduce their influence on human health. It is becoming even more important to



(a) Radiation absorption by mobile phone (b) Tissue name

Figure 1.1: Human head

identify the limits of safe exposure with respect to thermal hazards. The amount of radiofrequency energy absorbed by an organism depends on several factors such as frequency, the strength of radiofrequency radiation, and the duration of exposure. To calculate the increase of temperature in short-term exposure a general equation is used which has exposure time and heat capacity of the tissue. For long-time exposure, the linear equation cannot be applied for the detection of the temperature change. This time numerical equation has to be used. When the rate of energy absorption is relatively high, radiation produces heating in living tissue. Because of the increasing use of microwave transmission, sometimes at high power levels.

1.2.2 Mobile Phone Model

A mobile phone is a wireless handheld device that permits users to make and receive calls. It has different types of components. These components are interrelated to each other. The component of mobile phones is antenna, radio frequency component, printed circuit board (PCB), battery, side key, button, speaker, camera, touch liquid crystal Display (LCD) display. The front, back and side view structure of mobile phone is view at Figure 1.2. While the earliest generation of mobile phones could only make and receive calls, today's mobile phones do a lot more, accommodating web browsers, games, cameras, video players and navigational systems. A mobile phone typically operates on a cellular network, which is composed of cell sites scattered throughout cities, countryside's and even mountainous regions. If a user happens to be located in an area where there is no signal from any cell site belonging to the cellular network provider he or she is subscribed to, calls cannot be placed or received in that location. The 4G telecommunications network pioneered an all-internet transmission system using things like smart antenna arrays and point-to-point network fabrics. 4G relied on IP transmission, rather than traditional telephone circuit switching, which led to certain reception and transmission efficiencies. Now, a dominant model called 5G is being unrolled throughout the world. The 5G system uses higher frequency waves and a closer cell structure, which changes the networking style and promises greater bandwidth for users.

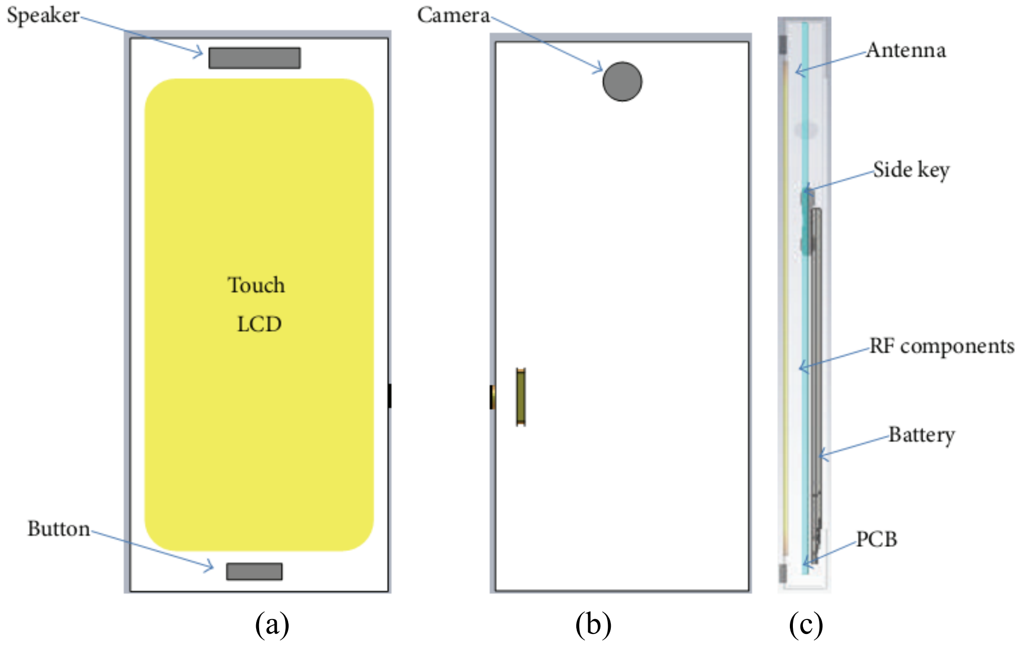


Figure 1.2: Structure of mobile phone: (a) front, (b) back and (c) side view

1.2.3 Electromagnetic Radiation and Spectrum

Electromagnetic radiation is the process of transmission the energy within the any type of waves or particles through space or through medium. It is a procedure of energy emitted and absorbed by charged elements, which shows wave- like behavior as it travels over space. It incorporates radio waves, microwaves, infrared, visible light, bright and gamma radiation. Traditionally, electromagnetic radiation comprises of EM waves, which are synchronized motions of electric and magnetic fields that travel at the speed of light through a vacuum. The two fields oscillate perpendicular to each other and perpendicular to the direction of wave propagation and energy, thus forming what is called a transverse wave. The electromagnetic spectrum is the graphical representation of presentation the range of frequencies of electromagnetic radiation and their particular wavelengths. Figure 1.3 is shown the Electromagnetic (EM) Spectrum. The radio spectrum falls in the electromagnetic spectrum from 3 Hz to 3000 GHz. The Electromagnetic waves in this range of frequency are known as radio waves. They are used widely in modern technology, especially in the telecommunication industry.

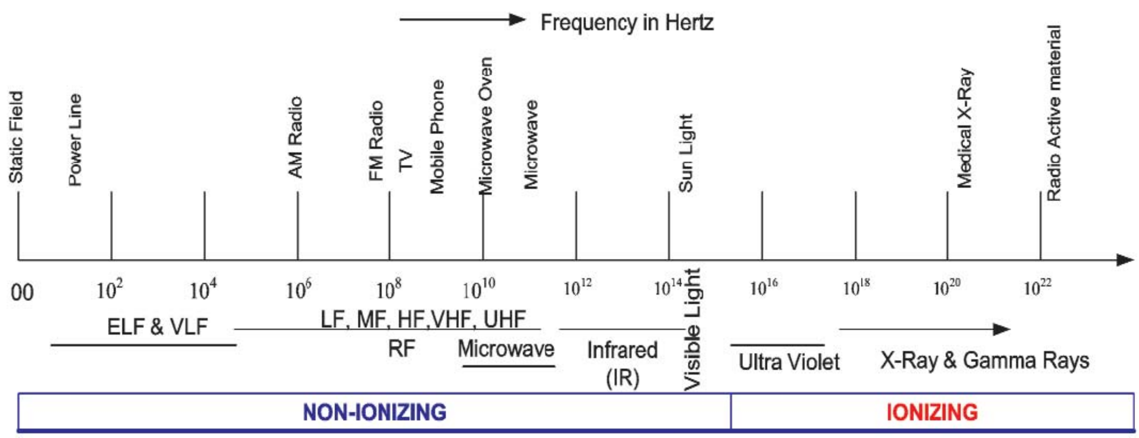


Figure 1.3: Electromagnetic (EM) Spectrum

The generation and transmission of radio waves are strictly regulated by national laws, laid out and enforced by the international body, the International Telecommunication Union (ITU) to avoid any interference between two separate users. In mobile communication system two-way electromagnetic radiation is used, one for transition and another for receive the signals. Radiation can be two types. One is non-ionizing radiation and another is ionizing radiation. The ionizing radiation has sufficient energy to interruption a chemical bond. It has high energy to break up the nucleus of atoms. Ionization is the process where a molecule is given enough energy to break it away from the particle. The non-ionizing radiation refers to the electromagnetic radiation that does not have enough energy to ionize atoms or molecules. Mobile phone frequency falls under the non-ionizing radiation. This non-ionizing radiation can cause living tissue damage because of heating effects. The electromagnetic radiation exposure depends on the below things:

a) Frequency of the electromagnetic signal,
b) Radiated power of mobile phone,
c) Duration of exposure
d) Distance of mobile phone
e) Electromagnetic signal strength
f) Temperature and humidity.

1.2.4 Specific Absorption Rate

Specific Absorption Rate (SAR) is a dosimetry quantity which defined as the rate of radio frequency power absorbed per unit mass by any part of the body. It measures the amount of power absorbed by the mass tissue and determined for either 1 g or 10 g of tissue in the shape of a cube [1]. SAR investigation is a domain that mandates a source and an exposure area. The source is usually a radiating structure directed towards a vital part of a human body that is vulnerable to severe biological effects of constant exposure. It typically specified at the maximum transmission power. Radiated power is higher when the mobile phone used in the area with a very low field strength of received signals. Thermal radiation of the mobile phone is also related to the SAR. Factors influencing SAR is given below.

a) SAR of a mobile phone depends on the mobile network carrier characteristics of the mobile phone and the antenna used its positioning and the total radiated power.
b) SAR values are dependent on the distance between the body and the mobile phones. As closer distance SAR provide higher value and vice versa.
c) SAR is affected by the dielectric properties of human health. Increased SAR is observed due to increase in conductivity and decrease in permittivity of human head.

SAR analysis entails three primary steps: An investigation of the scenario with SAR parameters. The estimation technique with computational methods. To reduce the SAR parameters on different levels. FCC sets SAR limit by 1.6W/kg [2]. European Union Council suggested SAR by 2.0W/kg [3].

1.3 PROBLEM STATEMENT

In this modern world, everyone uses mobile phones. When a mobile phone is in operation, it will transmit electromagnetic waves and a substantial part of them will be absorbed by human bodies, especially human heads. There are different generations of mobile phones such as 1G, 2G, 3G, 4G, 5G. One generation uses different types of frequency and radiated power. It is unknown what kind of changes occur in the human tissues according to the radiated power and frequency. By analyzing the SAR value for different frequencies are help to find out how this radiation affects the tissue. The SAR comparison of a different generation is also unknown, this paper helps to find out this comparison. Many numerical methods such as FDTD, FEM etc. are used to find the SAR value. This method is implemented in simulation software such as COMSOL and CST. The simulated result does not always provide accurate information. But mathematical equation and real time data for different tissue provides more accurate information. So, this paper use thermotical equations for finding the SAR. Today the child uses mobile phone for a long time. They become addicted by mobile phone. The absorption rate for child tissue is unknown. The exposure of high-intensity electromagnetic waves in the ultra-high frequency range generates heat, which can cause thermal damage to the brain, especially in children. No mathematical computation or comparison is shown about who is more affected by radiation between adult and child. This paper calculated the SAR with the help of real time data and shown the comparison of SAR between child and adult that helps to find out who is more affected by mobile phone radiation. The most immediate adverse effect of radiation is the increment of the temperature of tissues and organs. The increase of temperature in tissues can be calculated in two ways, one is short-term exposure and another is long-term exposure. In short-term exposure, high-frequency electromagnetic radiation is delivered to the body for a very short period of time. Previous research paper only shows the long-term exposure. But short-term exposure has also health hazards on human tissue. In this paper, short time exposures are calculated. The USA, Japan, Canada, Korea, China, and many other developed countries have set their limits for electromagnetic radiation. But Bangladesh has not yet done. The safety distance and radiated power from the mobile phone are not properly described in Bangladesh. This paper adds some contribution in this regard.

1.4 OBJECTIVES

This research paper develop model for calculating the specific absorption rate of mobile phone which is help to understand the mobile phone radiation effect on human body. The objectives of the research are as follows:

a) To measure the specific absorption rate for different mobile generations using a mathematical equation.
b) To identify the radiation effect on adult and child tissue.
c) To find out how the mobile phone radiation effects on human body.
d) To determine the safety aspects from mobile phone radiation.
e) To provide valuable information that will play a vital role in mobile communication system in Bangladesh.

1.5 SCOPE OF THE STUDY

In order to measure the specific absorption rate, it is important to identify the proper parameter for calculation. There are many ways to calculate the specific absorption rate. This paper calculated the specific absorption rate using electric field strength, mass density and tissue conductivity. Generally, the target data is collected first then store in the Microsoft excel and MATLAB. After primary data collection, data is analyzing, rectifying, altering, and exhibiting for determining useful information. Calculate the SAR for different frequencies with the help of theoretical equation. In this analysis the calculated SAR for different tissues is tested with international standard and find those value which violate the international standard. Mobile phone electromagnetic radiation detection circuit is design for determining the emitted power from different mobile phone generation. Finally discuss the safety guidelines for mobile phone electromagnetic radiation. The required tools to carry out this work are:

a) MATLAB,
b) Microsoft excel and
c) NI multisim software.

1.6 ORGANIZATION OF THE THESIS

This thesis consists of five chapters and these chapters are organized as follows:
Chapter 1 - Introduction: The introductory chapter describes the importance of the work that has been done, classification of electromagnetic radiation, problem statement, objective, scope and thesis organization of the work.
Chapter 2 - Literature Review: This chapter is about some review of related work. It gives the information about the contribution of several researches in this field.
Chapter 3 – Methodology: In this chapter an overview on methodology and experimentation is provided. Data collection, analysis, calculation, research tool, model and evaluating criteria is also discussed in details.
Chapter 4- Results and Discussions: The results and discussions chapter represent the outcome and details explanation which is obtained from methodology. This chapter include the graphical representation and comparisons of specific absorption rate with proper safety guidelines
Chapter 5- Conclusion: Contribution of this study and scope of future work are discussed in this chapter along with final conclusion of the thesis work.
Organization of these five chapters are illustrated in Figure 1.4.

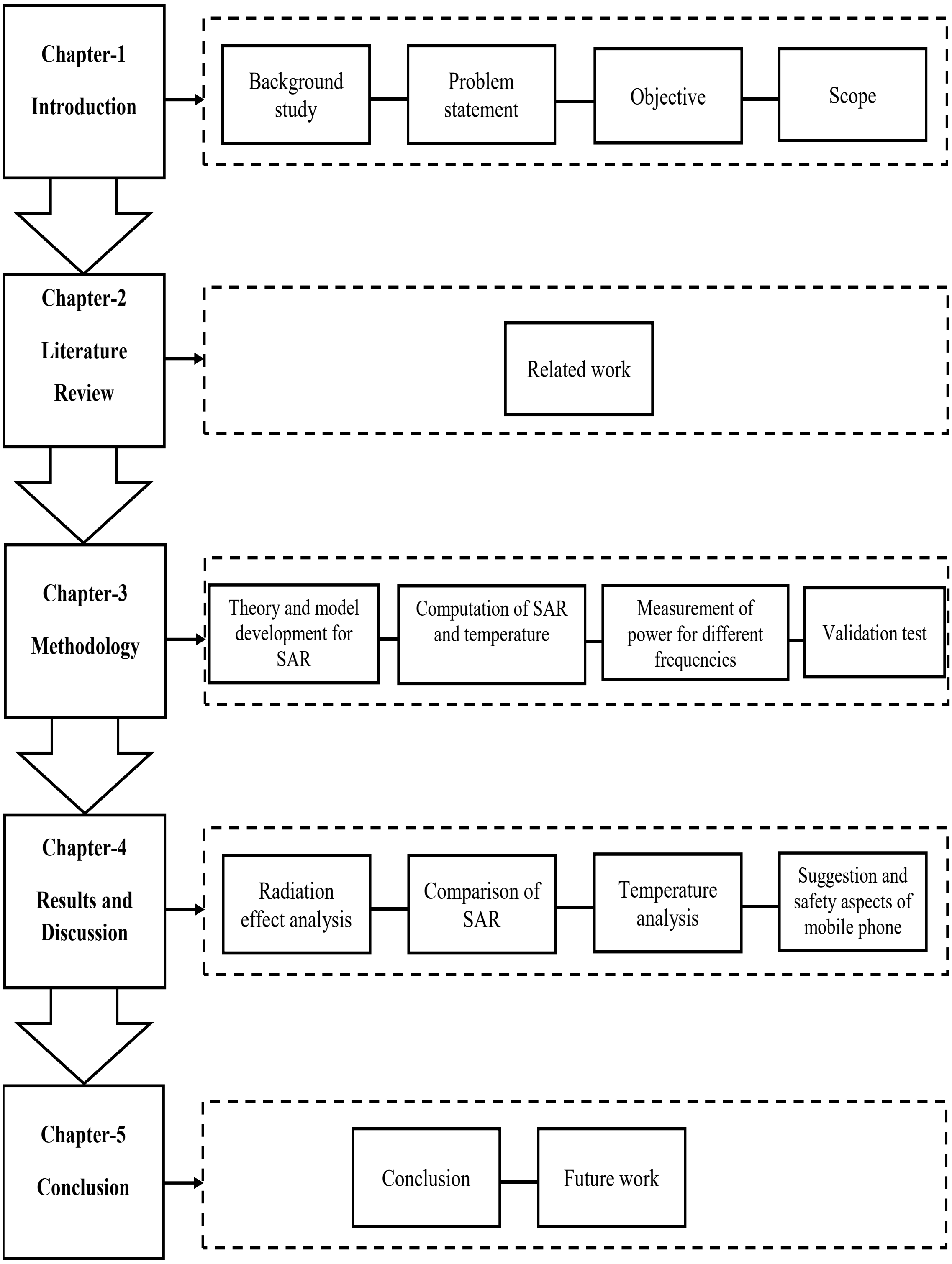


Figure 1.4: Organization of the thesis

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of past research efforts related with electromagnetic radiation of mobile phone. This chapter firstly discusses the SAR measurement process and the radiation effect on human body. Finally discuss the limitation of previous work.

2.2 RELATED WORK

Kun Zhao et al. in 2013 reports a study of specific absorption rate for LTE MIMO antennas in mobile phones [4]. The simulations were carried for SAM head phantom and a flat phantom. Four types of antennas are used for different position and under LTE frequency when the ground plane length varies from 90 to 150 mm. The SAR, value measure with the help of CST 2011 software and calculated all value are below the FCC standard. Ryota Takei et al. in 2017 identified the health hazards associated with exposure to electromagnetic waves from mobile phone. This paper estimated the specific absorption rate of electromagnetic radiation by numerical simulation of 3G mobile phone and computational human models with the anatomical structures of Japanese male and female. SAR value is considered for various positions for various tilt angle. SAR values were higher for the male model than for the female model [5]. Finally developed a high-fidelity CAD-based smartphone model based on 3G communication systems. Deepshikha Bhargava et al. in 2019 found the adverse effect on human health accidental overexposure to non-standard mobile phone radiation. It envisaged the physical effect of radio effect on human head. They found a small temperature increase in the delicate organs or tissues such as eyes, brain, skin [6]. Here analyzed the effect of overexposure of mobile phone radiation on the specific absorption rate (SAR) and temperature increase in three-dimensional heterogeneous human head models at 900 MHz frequency and 5 W radiating power.

Bogdan-Dumitru Alistar et al. extracted the existing the average values of electric permittivity and conductivity for the foremost types of tissue composing the head, mostly the electric permittivity and electric conductivity [7]. These values were used by calculating skin depth, the essential parameter assessing the penetration of the frequently encountered electromagnetic carriers for the wireless traffic: 410 MHz, 900 MHz ,1800 MHz ,1890 MHz ,2100 MHz. The paper presented a comparative analysis of the computed SAR using CST software, for the human head SAM phantom. Huanhuan Zhang in 2018 used algebraic approaches for electromagnetic and thermal investigation. Most of the existing studies used finite difference time domain method for calculating the electromagnetic and thermal analysis [8]. Electromagnetic and thermal co-simulation of human head model exposed to cell phones based on FEM method was studied in this paper. Mutually the convective and radiative edge situations were espoused during the thermal simulation phase. Ahmed Mohammed Ahmed in 2018 design a square patch antenna (SPA) simulated and evaluated at 2.4 GHz for internet application by using CST Microwave studio 2014. Square patch antennas (SPA) were broadly used with a general frequency of 2.4 GHz. Measures the Specific absorption rate (SAR) exposure of human to EM radiation of communication antenna [9]. This antenna produced the low SAR levels in adult head comparison with the children's tissues. Teerapot Wessapan et al. in 2013 presented arithmetical investigation of the specific absorption rate (SAR) and the heat transfer in a heterogeneous human eye model exposed to electromagnetic (EM) fields of 900 and 1800MHz. The highest SAR values were found in the cornea, and the highest temperature at the frequency of 900MHz was in the anterior chamber [10]. The temperature spreading in the eye induced by EM fields was not directly related to the SAR distribution due to the dielectric element and thermal properties. Bindhu Christopher et al. in 2020 experimented the exposures to electromagnetic radiation mainly from the extended use of mobile phones may initiate biological damages in the human body at the macromolecular level. Several studies applied on human and animal models and found significant changes in the functions of neural cells. Present study analyses the thermal changes and the specific absorption rates (SAR) of brain, eye and skin tissues due to protracted exposure to mobile phone radiation. A simulating human head with different human tissue was used for the study. The Phantom was exposed to radiation for longer durations and the temperature variations at different specific points were studied with sensitive thermocouple probes. The average rise in brain temperature and SAR was found to be very high [11]. The increase in temperature for eye and skin was also very high. Teerapot Wessapan et al. in 2012 presented numerical analysis for specific absorption rate and change in temperature distributions at 900 and 1800 MHz radio frequency radiation. The effects mobile phone radiation analysis with the help of specific absorption rate and temperature profile. For both frequencies, the highest SAR values were found in the area of the skin close the antenna. It is found that the highest SAR values are calculated for 1800MHz which SAR value is 1.187 W/kg. For 900MHz the SAR value is 0.823 [12]. In addition, this analysis shown that the temperature change was not directly proportion to the SAR value. Dragan Poljak in 2017 analysis the electromagnetic-thermal dosimetry systems for the valuation of human exposure to high frequency electromagnetic fields. The analysis approaches are based on certain integral and differential equation inventions and related numerical solution procedures for the control of specific absorption rate (SAR) and related temperature increase in a tissue. Maximum SAR value was found for eye and brain. Also, some numerical outcomes for the transcranial magnetic stimulus were presented. The exposure situations were examined by answering the foremost equations arising from the electromagnetic dosimetry via the mixture of FEM and MoM approach [13]. Illustrative computational examples was related to the assessment of SAR in the eye and brain due to the plane wave exposure and to the induced field in the brain due to the TMS treatment.

Sabbah et al. in 2011 used the finite difference time domain (FDTD) method for finding the specific absorption rate (SAR) distributions and temperature increase. Here use the multi-layered human head model exposed to the radiated from cellular phones antenna. In addition, the closer area of cellular phones is also studied. For the same levels of radiated power, SAR value were less than the safety limit recommendations, except in skin tissues. In this paper the maximum temperature was found at brain region [14]. Vladimir Stankovicl et al. in 2015 investigated the thermal outcomes on human head from mobile phones. This paper shown the temperature distribution and SAR at surface of human head close to source of electromagnetic radiation [15]. Finally, the results of simulation were related with investigational results. Naturally, the highest radiation level was in the area next to the phone antenna and gradually decreases with every subsequent area. Therefore, it can be concluded that the radiation energy is mostly absorbed in surface layers of the human head. Most of this absorbed energy is converted into heat, which results to an increase in temperature in biological tissues.

Mushtaq Ahmed Bhat et al. in 2015 calculated the change in temperature of skin, blood, muscle and bone tissue at the frequency of 800, 900, 1800 and 2450 MHz [16]. The 2 W radiated power from the antenna of mobile phone was consider. The calculation was made at the various depths and distance from the mobile phone. The skin depth from 0.1 to 0.5 mm was considered. Different duration of mobile phone exposure such as 15,30,45 and 60 minutes was taken for calculated the change in temperature. Highest temperature was found for 2450 MHz for skin tissue. Teerapot Wessapan et al. in 2012 provided a numerical analysis for specific absorption rate and heat transfer change in the human eye model due to exposure of mobile phone radiation. Here investigate the temperature change using power density of radiated mobile phone. For heat transfer analysis two model such as ordinary convection and porous media theory are uses. In all cases, the temperatures found from the established heat transfer model have a lower temperature than that of the conventional heat transfer model. The specific absorption rates and the change in temperature distribution for several tissue of the human eye through exposure to electromagnetic fields at 900 MHz, obtained by numerical resolution of electromagnetic wave circulation are presented [17]. The results show that the developed heat transfer model, was the provide more accurate way to determine the change in temperature. Moreover, it was found that the temperature distributions in human eye are not directly related to the SAR distribution due to the effect of dielectric properties, thermal properties and penetration depth of the electromagnetic power. Therefore, health effect was found due to assessment of electromagnetic field exposure. Jafar Keshvari et al. in 2006 frequent studies have endeavored to discoursed the enquiry of the radio frequency energy absorption between children and adults using computational methods. This paper implicit the similar dielectric parameters for child and adult head representations in SAR calculations. Here calculates the difference of specific absorption amount in the head area of children and adults by applying the finite-difference time-domain (FDTD) method for frequency 900,1800 and 2450 MHz. The conductivity and permittivity of all tissues were increased due to the high electromagnetic radiation. A half-wave dipole antenna was used for this calculation with different position. Due to change of dielectric values the SAR value is also changed. The calculated SAR value for specific averaging masses such as 1 g, 5 g or 10 g this may increase or decrease depending on the anatomy of the exposed region [18]. SAR variation is frequency dependent viewing that by increasing the dielectric values SAR value variations were not the same between the particular frequencies. Shamsi et al. in 2006 presented a complete numerical study of specific absorption rate (SAR) and temperature growth calculations for pregnant female due to exposed of radiation. This study was used for nine pregnant female models with different pregnant stages. SAR and temperature increase within and around fetuses at different pregnancy stages were calculated for two operating modes such as normal mode and first-level controlled mode at 64 and 128 MHz [19]. Local fetus energy statement beats the limit of 10 W/kg in the first-level controlled mode at 64 MHz. Fatih Kaburcuk in 2019 explored the effects of a brain tumor situated in a dispersive human head model on specific absorption rate (SAR) and temperature growth due to different types of radio frequency sources at 4G and 5G. Here used Multiphysics model to analyzes the dispersive human head with the brain tumor. Also provided the SAR and temperature rise distributions in the head due to the radio frequency source functioned at 4G and 5G cellular frequencies in a single finite-difference time-domain simulation. Numerical results confirmation that the brain tumor in the head affected by radio frequency sources at 4G and 5G cellular frequencies [20].

Ezequiel et al. in 2018 use the FDTD method for SAR distribution in two models of head one is heterogeneous and another is homogenous. Analysis the data using statistical method. In the first layers, skin and muscle the SAR values found are almost the same but in internal tissues as gray and white matter SAR distribution is different [21].

Jemima Priyadarshini et al. in 2017 intends a survey for analysis the radio frequency effect. Here also focus on exposure areas on the human body using specific absorption rate. The SAR depends on dielectric parameters. The paper shown decrease methodologies and its main advantages and specifics probable setbacks. The study specifies a necessity of the specific radiation structure for a specific zone of exposure of concern, followed by an essential of perfect decrease methodology [22]. Radouane Karli et al. in 2014 shown a comparative study of diploe and patch antennas commonly used for 900, 1800 and 2450 MHz. This study recognizes the possessions of electromagnetic waves on human head model.The objective was to evaluate the SAR in simulation anatomic based model of the human head for changed antenna head distances and in several frequency. All numerical simulations outcomes were done using Ansys HFSS software [23]. This study explained local SAR in the human head exposed to mobile phone radiation at different frequencies with distances. Khalatbari et al. in 2006 focused on two techniques for calculating the SAR value. One was experimental measurements and another was finite-difference time-domain computations. Here shown the mobile phones radiations at 900 and 1800 MHz. Computed value was compared with a realistic head model. The SAR value cross the international safety limit for different human head tissue at 1W radiated power from the antenna. The results indicated the area of the maximum local SAR was found for skin and muscle [24]. Md. Ikbal Hossain et al. studied the effects of PIFA antenna on human body due to electromagnetic (EM) absorption and also analysis the performances. The evaluation was conducted using two parameters such as SAR and total absorption power on tissue. The cheek and tilt positions of mobile phone also affect the total absorption power. The results shown that the high SAR and absorbed power into a human had a bad effect [25]. P.K. Dutta et al. in 2016 analysis the performance of the mobile phone antenna due to diferent shields. Proper shielding material properties are found for aluminuam. It has been observed that the shield can be positioned inside or outside of the mobile phone and same performance of the mobile phone antenna and SAR reduction was achieved [26]. Khurana V. G. et al. in 2009 specify that using a cell phone for ≥10 years nearly doubles the risk of being analyzed with a brain tumor on the similar side of the head as that preferred for cell phone use [27]. The data realize numerical implication for glioma and acoustic neuroma but not for meningioma. The authors accomplish that there was satisfactory epidemiologic indication to recommend a link between continued cell phone usage and the growth of an ipsilateral brain tumor.

2.3 LIMITATION OF PREVIOUS WORK

Previous research work has some limitation. The limitation of previous works are listed below:

a) SAR values were calculated only for specific generation, tissue and distance.

b) For calculating the SAR, simulated software was used. Multiple condition implementation is not so easy in simulated software. So, getting an accurate answer is very hard.
c) High radiated power such as 2W, 3W,4W,5W,20W etc. from mobile phone was consider. But generally mobile phone emits less power than that.
d) For analysis the effect of mobile phone radiation previous paper used fixed dielectric data. But the dielectric property value such as permittivity, mass density and conductivity of tissues are not fixed for all tissue.
e) It was not clearly explained how child tissue are more affected by mobile phone radiation.
f) Tissue temperature changes can be measure in two ways one for short term and another for long term. Previous paper used only long-term changes.
g) Some paper indicate radiation has bad impacts and another paper indicates it has no bad impacts. This paper provides a valuables solution.

2.4 SUMMERY

The analysis of literature review helps to take necessary step for calculating the electromagnetic value of mobile phone. The information and finding are used as guidance to select the important parameter.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter gives a framework of research process that were followed in the study. Here discuss the measurement process of the absorption rate of radio frequency energy or electromagnetic field by the human body when exposed to wireless devices such as mobile phone. Firstly, discuss the theory and model to calculate specific absorption rate. Secondly, discuss the data collection and SAR calculation process by replacing the data from second generation to fifth generation. Thirdly, design a circuit that can detect the power for a different generation. Finally, discuss the validation process of the calculated data.

3.2 WORK FLOW DIAGRAM

Work flow is the formalized graphic representation of a logical sequence of work process. It shows the sequence of movements, functions or actions. Generally, mathematical equation is developed for calculate the SAR and temperature. This approach evaluates the specific absorption rate and change in temperature distributions in human head tissues due to the use of 2G,3G.4G and 5G phones. Values are calculated for human head tissues considering a model of six homogenous tissue layers human head, and single direction mobile phone antenna that is assumed to be located 5mm, 20mm, 40mm, 60mm, 80mm and 100mm away from the user head. Mobile phone use different radiated power. This power is not fixed for all time. It's radiated power depend on some parameter. This paper analysis with four types of radiated power such as 0.125W,0.250W,1W and 2 W. This range is minimum and maximum value for mobile phone. Some data such as mass density, heat capacity and tissue conductivity are collected first and other data such as electric field strength, penetration depth is calculated. After primary data collection data analysis is done. Then Calculate the SAR for different frequencies with the help of equation The logical sequence of work process is shown in Figure 3.1, which consists of work flow of data collection, classifying the data, data processing, data analysis and

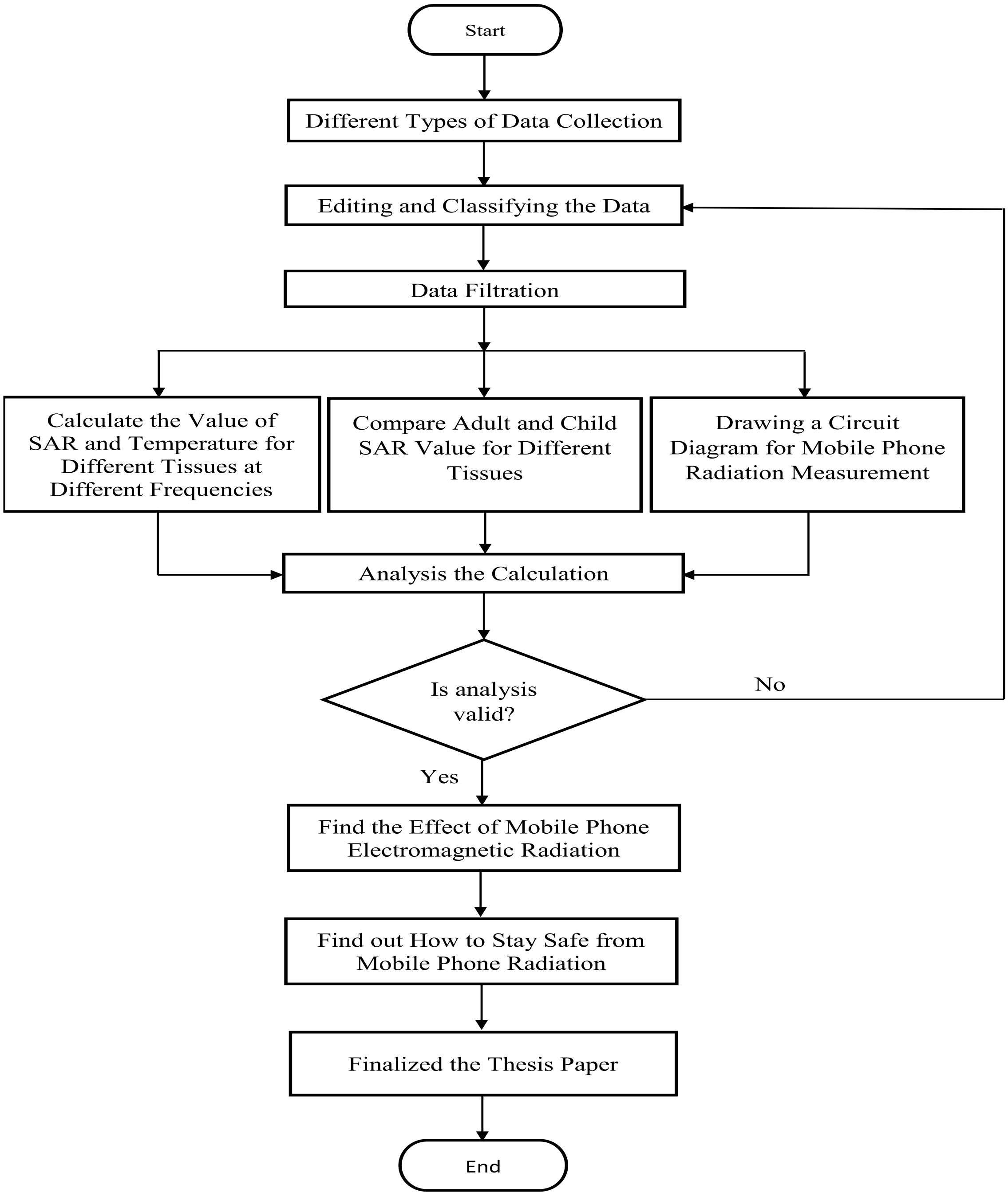


Figure 3.1: Work flow diagram

verifications steps. Mobile phone electromagnetic radiation detection circuit is design for determining the emitted power. The measuring of SAR is important for finding the effect and safety guidelines from mobile phone electromagnetic radiation.

3.3 EQUATION OF SPECIFIC ABSORPTION RATE

Electromagnetic wave of mobile phone can penetrate into the human body. Specific absorption rate can measure this absorbed rate. It can be defined as the power absorbed per mass of tissue with the units of watts per kilogram (W/Kg). SAR can find over the entire body or over a small sample volume. The biological effects rise due to producing the heat. In order to estimate the probable risk for human health due to mobile phone usage, it is needed to assess SAR distribution on human head exposed to electromagnetic radiation during the time spent using the mobile phone. SAR is found by human mass density, electric field strength, and tissue conductivity. Tissue conductivity is a biophysical indication of tissue construction and functioning. It is the measure of the ease at which an electromagnetic wave can pass through tissue. The mass density of a tissue is defined as its mass per unit of volume. The visual representation of SAR parameter is shown in Figure 3.2, which consists of the parameter such as mass density, electric field strength, and tissue conductivity. Electric field strength depends on impedance and power density. Impedance depends on relative permittivity and permeability. Power density identify by radiated power and distance. For proper calculation two type distance is taken one is penetration depth and another is distance form mobile phone. SAR can be express as mass density, tissue conductivity and electric field strength [28]. For electric field strength, mass density and tissue conductivity SAR can be expressed as –

$$\mathrm{SAR} = \frac{\sigma\,|E|^2}{2\,\rho} \tag{3.1}$$

where,

σ = Tissue conductivity (S/m)

ρ =Human mass density (kg/m^3)

E = Electric field strength (V/m).

Electric field strength is a mathematical expression of the intensity of an electrical field at a specific position. The standard unit of electric field strength is volt per meter (v/m). It can be determined by power density and medium impedance. Power density is the amount of power per unit volume and it is expressed as W/m^3. How much the circuit impedes the flow of charge is determined by impedance and expressed as ohm(Ω).

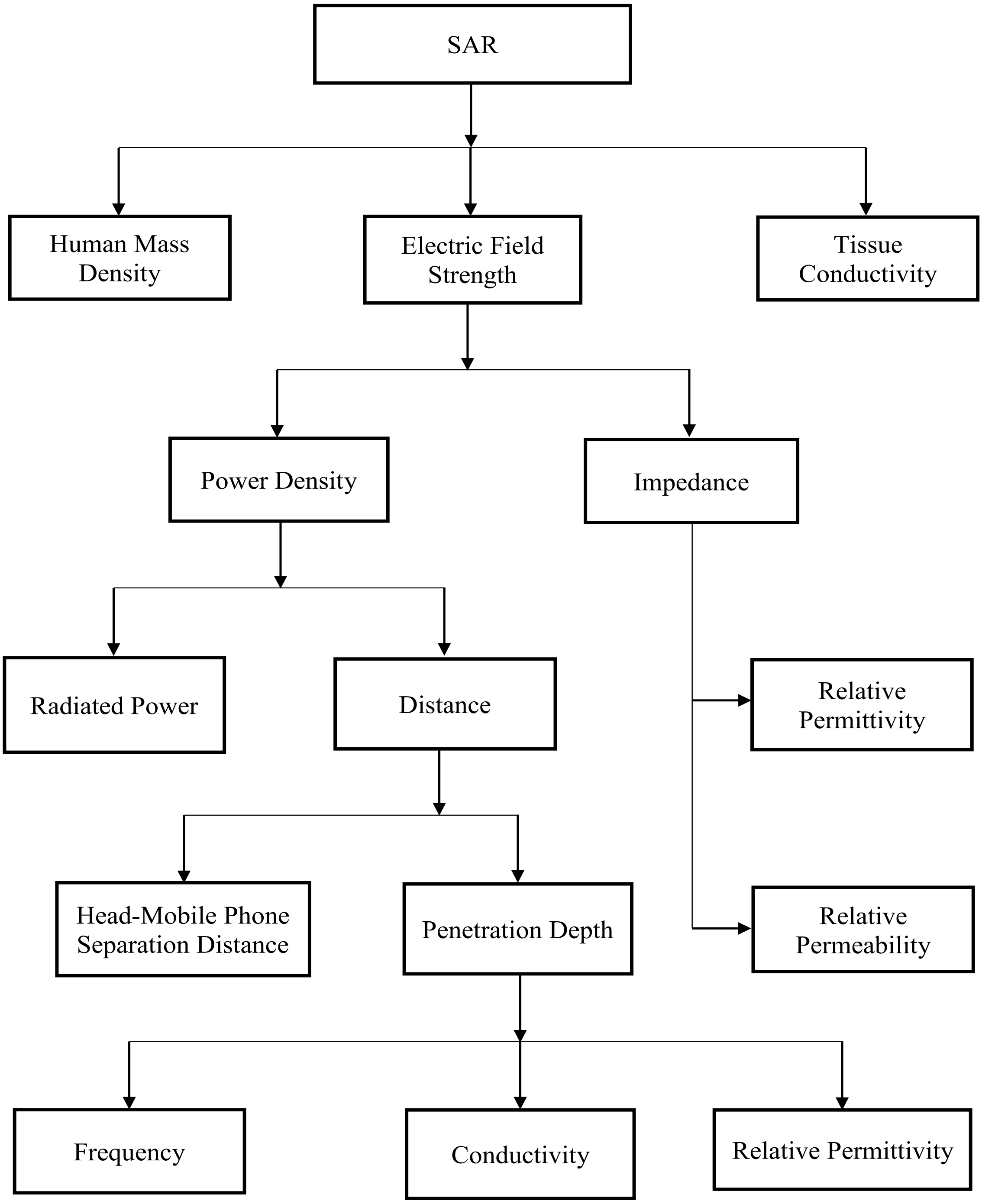


Figure 3.2: Parameter for SAR calculation

For power density S and the medium impedance η the electric field strength (E) is relating by the equation [29]-

$$E = \sqrt{s\eta} \tag{3.2}$$

The impedance of the tissues (η) is related with permeability and permittivity which can be determined by the following formula.

$$\eta = \eta_0 \sqrt{\frac{\mu_r}{\varepsilon_r}} \tag{3.3}$$

where,

η_0 = Free space impedance(Ω)

μ_r= Relative permeability

ε_r = Relative permittivity or dielectric constant.

For free space the impedance η_0 and $\mu_r$can be written as 377 Ω and 1 respectively [30]. Substitution this value in equation (3.3), the impedance can be written as-

$$\eta = 377\sqrt{\frac{1}{\varepsilon_r}} \tag{3.4}$$

To calculate the power density on the surface of an imaginary sphere surrounding the radio frequency source can be expressed as [31]-

$$S = \frac{P}{4\pi d^2} \tag{3.5}$$

where,

d = Diameter of the imaginary sphere (m)

P = Total power at the source (W) and

S = Power density on the surface of the sphere (W/m^2)

The diameter is the combination of penetration depth (δ) and the head-antenna separation distance (l). So, the equation (3.5) can be written as-

$$S = \frac{P}{4\pi(\delta + l)^2} \tag{3.6}$$

Penetration depth is the process of measurement how deeply electromagnetic radiation can penetrate into a tissue. For biological materials the general expression for the penetration depth or skin depth at angular frequency ω can be determined as-

$$\delta = \frac{1}{\omega}[(\frac{\mu_0 \varepsilon_r \varepsilon_0}{2})(\sqrt{1 + (\frac{\sigma}{\omega \varepsilon_r \varepsilon_0})^2} - 1)]^{-1/2} \tag{3.7}$$

where,

ω = Angular frequency

μ_0 = Free space permeability

ε_0 = Free space permittivity

ε_r = Relative permittivity

σ = Conductivity of the medium.

For calculating the penetration depth, the value of angular frequency $\omega = 2\pi f$ (radians/s), free-space permeability $\mu_0 = 4\pi \times 10^{-7}$(H/m) and free space permittivity $\varepsilon_0 = 8.85 \times 10^{-12}$(F/m). Substitution this value in equation (3.7), then the penetration depth can be expressed as-

$$\delta = \frac{1}{2\pi f}[(\frac{4\pi \times 10^{-7} \times \varepsilon_r \times 8.85 \times 10^{-12}}{2})(\sqrt{1 + (\frac{\sigma}{2\pi f \times \varepsilon_r \times 8.85 \times 10^{-12}})^2} - 1)]^{-1/2} \tag{3.8}$$

Substitute the value of penetration depth(δ) in equation (3.6) then the power density can be written as-

$$S = \frac{P}{4\pi((\frac{1}{2\pi f}[(\frac{4\pi \times 10^{-7} \times \varepsilon_r \times 8.85 \times 10^{-12}}{2})(\sqrt{1+(\frac{\sigma}{2\pi f \times \varepsilon_r \times 8.85 \times 10^{-12}})^2} - 1)]^{-1/2}) + l)^2} \tag{3.9}$$

By putting the value of equation (3.4) and (3.9) into the equation (3.2) the electric field strength for human tissue can be expressed as-

$$E = \sqrt{\frac{P}{4\pi((\frac{1}{2\pi f}[(\frac{4\pi \times 10^{-7} \times \varepsilon_r \times 8.85 \times 10^{-12}}{2})(\sqrt{1+(\frac{\sigma}{2\pi f \times \varepsilon_r \times 8.85 \times 10^{-12}})^2} - 1)]^{-1/2}) + l)^2} * 377\sqrt{\frac{1}{\varepsilon_r}}} \tag{3.10}$$

Replacing the electric field strength value into equation (3.1), the SAR for human tissue can be easily written as-

$$\text{SAR} = \frac{\sigma \left| \sqrt{\frac{P}{4\pi((\frac{1}{2\pi f}[(\frac{4\pi \times 10^{-7} \times \varepsilon_r \times 8.85 \times 10^{-12}}{2})(\sqrt{1+(\frac{\sigma}{2\pi f \times \varepsilon_r \times 8.85 \times 10^{-12}})^2} - 1)]^{-1/2})+1)^2} * 377 \sqrt{\frac{1}{\varepsilon_r}}} \right|^2}{2\,\rho} \tag{3.11}$$

The absorption of the electromagnetic radiation produces temperature change of the human tissue. Tissue temperature depend on SAR and the exposure of the time. Figure 3.3 shown the parameter of tissue temperature measurement, which consists of heat capacity, exposure of time and SAR.

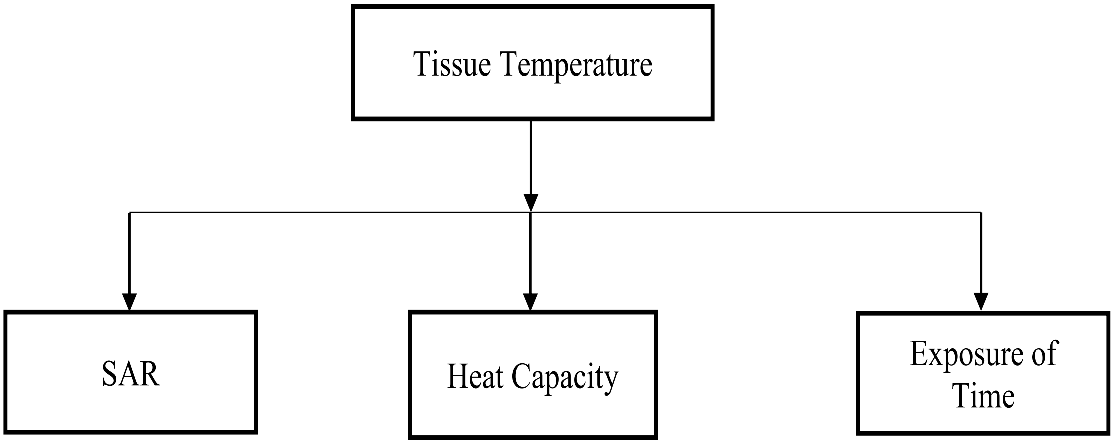


Figure 3.3: Parameter for temperature calculation

The equation for finding the temperature at a point can be express by the following equation-

$$T = \frac{SAR \times t}{C} \tag{3.12}$$

where,

T = Temperature (°C)

t = Exposure of time (s)

C = Heat Capacity (J/kg/°C)

SAR and temperature value can be easily calculated using equation (3.11) and (3.12). For solving this equation proper data selection is very important. If the data is invalid then the value of SAR and temperature is also invalid.

3.4 DATA COLLECTION

Data collection is an investigation module in all study field. It is a procedure for gathering and measuring information for targeted elements in a system, which then aids estimate the outcomes. Three types of data are required for this paper such as dielectric properties of each tissue, published research work information and data of IC (LM386), diode(1N3491) properties. Dielectric data is required for calculating SAR and temperate of different tissue. Published data help for validation test and find the effect of the mobile phone radiation. The IC and diode data assists to build up the electromagnetic radiation detection circuits and measure the power. The dielectric properties of the human tissues are conductivity, relative permittivity, mass density and heat capacity. This value changes for frequency. The dielectric data for 800 to 3600MHz collect from ITIS foundation [32]. Data sets for circuit components have been collected from Texas Instruments Incorporated [33].

3.5 MATLAB PROGRAM FOR FINDING SAR AND TEMPERATURE

The conceptional or mathematical representation of finding the specific absorption rate can be develop with the help of programming language. This model takes some input such as frequency, dielectric properties values. Finally shown the specific absorption rate and temperature value with respect to input. The source code of this model is attached below.

```
clc;
clear all;
close all;
Pi=3.1416;
%taking input from the user
f=input ('Enter the Value of Frequency (Hz):');
RP=input ('Enter the Relative Permittivity(F/m):');
EC=input ('Enter the Tissue Conductivity(S/m):');
D=input ('Enter the Mass Density of the Tissue((kg/m^3)):');
H=input ('Enter the Heat Capacity of the Tissue(J/kg/C):');
P=input ('Enter the Radiated Power of the mobile phone(W):');
```

```
Di=input ('Enter the Distance of Mobile Phone(mm):');
t=input ('Enter the Duration of Exposure (s):');
% Find penetration depth
PD=((1/(2*Pi*f))*((((4*Pi*10^-7*RP*8.85*10^-12)/2) * ( (sqrt (1+
((EC/(2*Pi*f*RP*8.85  *10^-12 ))^2)))-1))^(-1/2)));
%Find Power density on the surface of the sphere
E=(sqrt((P/(4*Pi*((PD+Di) ^2))) *(377*sqrt(1/RP))));
%Find SAR value
sar=((EC*(E^2))/(2*D));
%Find temperature value
Tem=((sar*t)/H);
%Print the SAR value
fprintf('For Frequency %d MHz Radiated Power %.3f W Distance %.3f mm\nSAR is :
= %f W/Kg\n',f,P,Di,sar);
fprintf('For %d second exposure\nTemperature change is: %f \n',t,Tem);
```

3.6 MATHEMATICAL COMPUTATION FOR SAR AND TEMPERATURE

Specific absorption rate and temperature value vary for frequency. One type of generation uses different type of frequencies. The computation of SAR has been performed for 2G to 5G mobile phone. With the help of equation (3.1) and (3.12) the value of SAR and change in temperature can be easily calculated. For computing this, the dielectric parameter (relative parameter of tissue, density, tissue conductivity, heat capacity), electric field strength, radiated power, distance between head antenna value is required.

3.6.1 For Second Generation(2G) Mobile Phone

2G mobile phone generally use 1800 MHz frequency. The average power for 2G mobile phone is 0.125W. Assuming that the head and antenna separation distance is 0 mm with exposure time 6 minutes. Using the equation (3.8) the maximum penetration depth of the skin tissue at 1800 MHz can be written as-

$$\delta = \frac{1}{2\pi f}\left[\left(\frac{4\pi \times 10^{-7} \times \varepsilon_r \times 8.85 \times 10^{-12}}{2}\right)\left(\sqrt{1+\left(\frac{\sigma}{2\pi f \times \varepsilon_r \times 8.85 \times 10^{-12}}\right)^2} - 1\right)\right]^{-1/2}$$

here,

Relative permittivity ε_r=38.9

Tissue conductivity σ=1.18 S/m

Frequency f=1800 $\times$ 10^6 Hz

So, the penetration depth can be written as-

$$\delta = \frac{1}{2\times 3.1416\times 1800\times 10^6}\left[\left(\frac{4\times 3.1416\times 10^{-7}\times 38.9\times 8.85\times 10^{-12}}{2}\right)\left(\sqrt{1+\left(\frac{1.18}{2\times 3.1416\times 1800\times 10^6\times 38.9\times 8.85\times 10^{-12}}\right)^2}-1\right)\right]^{-1/2}$$

$$\delta = 0.028 \text{ m}$$

The power density formed by the mobile phone at the penetration depth(δ) can be calculated by using the equation (3.6) as-

$$S = \frac{P}{4\pi(\delta+l)^2}$$

$$S = \frac{0.125}{4\times 3.1416(0.028+0)^2}$$

$$S = 12.68\ W/m^2$$

The impedance of the human head tissues (η) can be determined by the equation (3.4) as-

$$\eta = 377\sqrt{\frac{1}{\varepsilon_r}}$$

$$\eta = 377\sqrt{\frac{1}{38.9}}$$

$$\eta = 60.45\ \Omega$$

Induced electric field of the tissue are calculated by the equation (3.2) as-

$$E = \sqrt{s\eta}$$

$$E = \sqrt{12.68\times 60.45}$$

$$E = 27.69 \text{ V/m}$$

When the electric field distribution inside the head tissues is estimated, the SAR value can be easily calculated. The SAR in the skin can be calculated by the equation (3.1) as-

$$\text{SAR} = \frac{\sigma\,|E|^2}{2\,\rho}$$

$$\text{SAR} = \frac{1.18\times |27.69|^2}{2\times 1109}$$

$$\text{SAR} = 0.41 \text{ W/Kg}$$

This value is below from ICNIRP limit. Temperature of human head tissue can be calculated using equation (3.12).

$$T = \frac{SAR \times t}{C}$$

here,

Duration of exposure t= (6×60)=360 second

SAR=0.41 W/Kg

Heat capacity C=3391 J/kg/°C

So, the temperature can be written as-

$$T = \frac{0.41\times 360}{3391}$$

$$T = 0.04°C$$

For second generation mobile phone the SAR value of skin is 0.41W/Kg and temperature is 0.04°C. Using this process, the value of SAR and temperature for other human tissue such as fat, bone, brain, eye and muscle can be calculated.

3.6.2 For Third Generation (3G) Mobile Phone

3G mobile phone generally use 2100 MHz frequency. Assuming that the head and antenna separation distance is 0 m with exposure time 6 minutes. Using the equation (3.8) the maximum penetration depth of the skin tissue at 2100 MHz can be written as-

$$\delta = \frac{1}{2\pi f}\left[\left(\frac{4\pi\times 10^{-7}\times \varepsilon_r \times 8.85\times 10^{-12}}{2}\right)\left(\sqrt{1+\left(\frac{\sigma}{2\pi f\times \varepsilon_r\times 8.85\times 10^{-12}}\right)^2} - 1\right)\right]^{-1/2}$$

here,

Relative permittivity ε_r=38.4

Tissue conductivity σ=1.31 S/m

Frequency f=2100×10^6 Hz

So, the penetration depth can be written as-

$$\delta = \frac{1}{2\times3.1416\times2100\times10^{6}}[(\frac{4\times3.1416\times10^{-7}\times38.4\times8.85\times10^{-12}}{2})(\sqrt{1+(\frac{1.31}{2\times3.1416\times2100\times10^{6}\times38.4\times8.85\times10^{-12}})^{2}}-1)]^{-1/2}$$

$$\delta = 0.025 \text{ m}$$

If radiated power for 3G mobile phone is 0.125W. The power density formed by the mobile phone at the penetration depth(δ) can be calculated by using the equation (3.6) as-

$$S = \frac{P}{4\pi(\delta+l)^2}$$

$$S = \frac{0.125}{4\times3.1416(0.025+0)^2}$$

$$S = 15.92\ W/m^2$$

The impedance of the human head tissues (η) can be determined by the equation (3.4) as-

$$\eta = 377\sqrt{\frac{1}{\varepsilon_r}}$$

$$\eta = 377\sqrt{\frac{1}{38.4}}$$

$$\eta = 60.84\ \Omega$$

Induced electric field of the tissue are calculated by the equation (3.2) as-

$$E = \sqrt{s\eta}$$

$$E = \sqrt{15.92 \times 60.84}$$

$$E = 31.12 \text{ V/m}$$

When the electric field distribution inside the head tissues is estimated, the SAR value can be easily calculated. The SAR in the skin can be calculated by the equation (3.1) as-

$$SAR = \frac{\sigma\,|E|^2}{2\,\rho}$$

$$SAR = \frac{1.31\times|31.12|^2}{2\times1109}$$

$$SAR = 0.57 \text{ W/Kg}$$

This value is below from ICNIRP limit. Temperature of human head tissue can be calculated using equation (3.12).

$$T=\frac{SAR \times t}{C}$$

here,

Duration of exposure t= (6×60)=360 second

SAR=0.57 W/Kg

Heat capacity C=3391 J/kg/°C

So, the temperature can be written as-

$$T=\frac{0.57 \times 360}{3391}$$

$$T=0.06°C$$

For third generation mobile phone the SAR value of skin is 0.57W/Kg and temperature is 0.06°C.

3.6.3 For Fourth Generation(4G) Mobile Phone

4G mobile phone generally use 2600 MHz frequency. Assuming that the head and antenna separation distance is 0 m with exposure time 6 minutes. Using the equation (3.8) the maximum penetration depth of the skin tissue at 2600 MHz can be written as-

$$\delta = \frac{1}{2\pi f}\left[\left(\frac{4\pi \times 10^{-7} \times \varepsilon_r \times 8.85 \times 10^{-12}}{2}\right)\left(\sqrt{1+\left(\frac{\sigma}{2\pi f \times \varepsilon_r \times 8.85 \times 10^{-12}}\right)^2}-1\right)\right]^{-1/2}$$

here,

Frequency f=2600×10^6 Hz

Relative permittivity ε_r=37.8

Tissue conductivity σ=1.54 S/m

So, the penetration depth can be written as-

$$\delta = \frac{1}{2\times 3.1416\times 2600 \times 10^6}\left[\left(\frac{4\times 3.1416 \times 10^{-7} \times 37.8 \times 8.85 \times 10^{-12}}{2}\right)\left(\sqrt{1+\left(\frac{1.54}{2\times 3.1416\times 2600 \times 10^6 \times 37.8 \times 8.85 \times 10^{-12}}\right)^2}-1\right)\right]^{-1/2}$$

$$\delta = 0.021m$$

If radiated power for 4G mobile phone is 0.125W. The power density formed by the mobile phone at the penetration depth(δ) can be calculated by using the equation (3.6) as-

$$S= \frac{P}{4\pi(\delta+l)^2}$$

$$S = \frac{0.125}{4\times3.1416(0.021+0)^2}$$

$$S=22.56\ W/m^2$$

The impedance of the human head tissues (η) can be determined by the equation (3.4) as-

$$\eta = 377\sqrt{\frac{1}{\varepsilon_r}}$$

$$\eta = 377\sqrt{\frac{1}{37.8}}$$

$$\eta = 61.32\ \Omega$$

Induced electric field of the tissue are calculated by the equation (3.2) as-

$$E= \sqrt{s\eta}$$

$$E= \sqrt{22.56 \times 61.32}$$

$$E=37.19\ \text{V/m}$$

When the electric field distribution inside the head tissues is estimated, the SAR value can be easily calculated. The SAR in the skin can be calculated by the equation (3.1) as-

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

$$SAR\ = \frac{1.54\times\ |37.19|^2}{2\ \times1109}$$

$$SAR= 0.96\ \text{W/Kg}$$

This value is below from ICNIRP limit. Temperature of human head tissue can be calculated using equation (3.12).

$$T=\frac{SAR\ \times\ t}{C}$$

here,

Duration of exposure t= (6× 60)=360 second

SAR=0.96 W/Kg

Heat capacity C=3391 J/kg/°C

So, the temperature can be written as-

$$T=\frac{0.96 \times 360}{3391}$$

T=0.1°C

For fourth generation mobile phone the SAR value of skin is 0.96W/Kg and temperature is 0.1°C. The SAR value is increasing due to the higher frequency change. Different type of frequency use different type of dielectric value. Higher mobile technology uses higher frequency. So, the SAR value is higher for higher frequency or technology.

3.6.4 For Fifth Generation(5G) Mobile Phone

5G mobile phone generally use 3500 MHz frequency. Assuming that the head and antenna separation distance is 0 m with exposure time 6 minutes. Using the equation (3.8) the maximum penetration depth of the skin tissue at 3500 MHz can be written as-

$$\delta = \frac{1}{2\pi f}[(\frac{4\pi \times 10^{-7} \times \varepsilon_r \times 8.85 \times 10^{-12}}{2})(\sqrt{1+(\frac{\sigma}{2\pi f \times \varepsilon_r \times 8.85 \times 10^{-12}})^2}-1)]^{-1/2}$$

here,

Frequency f=3500×10^6 Hz

Relative permittivity ε_r=37

Tissue conductivity σ=2.02 S/m

So, the penetration depth can be written as-

$$\delta = \frac{1}{2\times 3.1416 \times 3500 \times 10^6}[(\frac{4\times 3.1416 \times 10^{-7} \times 37 \times 8.85 \times 10^{-12}}{2})(\sqrt{1+(\frac{2.02}{2\times 3.1416 \times 3500 \times 10^6 \times 37 \times 8.85 \times 10^{-12}})^2}-1)]^{-1/2}$$

$$\delta = 0.016 \text{ m}$$

If radiated power for 5G mobile phone is 0.125W. The power density formed by the mobile phone at the penetration depth(δ) can be calculated by using the equation (3.6) as-

$$S = \frac{P}{4\pi(\delta + l)^2}$$

$$S = \frac{0.125}{4 \times 3.1416(0.016+0)^2}$$

$$S = 38.86 \; W/m^2$$

The impedance of the tissues (η) can be determined by the equation (3.4) as-

$$\eta = 377\sqrt{\frac{1}{\varepsilon_r}}$$

$$\eta = 377\sqrt{\frac{1}{37}}$$

$$\eta = 61.98 \; \Omega$$

Induced electric field of the tissue are calculated by the equation (3.2) as-

$$E = \sqrt{s\eta}$$

$$E = \sqrt{38.86 \times 61.98}$$

$$E = 49.08 \text{ V/m}$$

When the electric field distribution inside the head tissues is estimated, the SAR value can be easily calculated. The SAR in the skin can be calculated by the equation (3.1) as-

$$SAR = \frac{\sigma \, |E|^2}{2 \, \rho}$$

$$SAR = \frac{2.02 \times |49.08|^2}{2 \times 1109}$$

$$SAR = 2.18 \text{ W/Kg}$$

This value crosses the ICNIRP limit. Temperature of human head tissue can be calculated using equation (3.12).

$$T = \frac{SAR \times \mathrm{t}}{C}$$

here,

Duration of exposure t= (6× 60)=360 second

SAR=2.18 W/Kg

Heat capacity C=3391 J/kg/°C

So, the temperature can be written as-

$$T = \frac{2.18 \times 360}{3391}$$

$$T=0.23°C$$

For fifth generation mobile phone the SAR value of skin is 2.18W/Kg and temperature is 0.23°C.

3.7 SIMULATION FOR MEASURE THE POWER

When mobile communication establishes the electromagnetic energy is used to create the connection. This electromagnetic power can be detected by a simulation software. A simulation is an inferential imitation of the activity of a system that represents its performance for a certain time. Multisim is a simulation software for circuit diagram design. Using this software any kind of circuit diagram can be design and run. In this paper IC (LM 386) and a diode(1N3491) are used to detect and measure the power of electromagnetic radiation for mobile phone. The circuit diagram for detecting the electromagnetic radiation is shown in Figure 3.4, which consists of LM386 IC,1N3491 diode, capacitor, function generation and LED light. Instead of mobile phone the function generator is used for frequency generate. Major circuit element for electromagnetic radiation detection is LM 386 IC (1), Function generator (1),1N3491 diode (2),10μF capacitor (1), LED light (1) and Antenna (1). The diode 1N3491 is used to rectify whatever frequency comes in. The most common function of a diode is to allow to pass electromagnetic radiation in one direction and blocking it in the opposite direction. It receives electromagnetic power from function generator. The pin diagram of LM386 IC is shown in Figure 3.5, which consist of total 8 pins such as input, output, gain, ground and bypass.

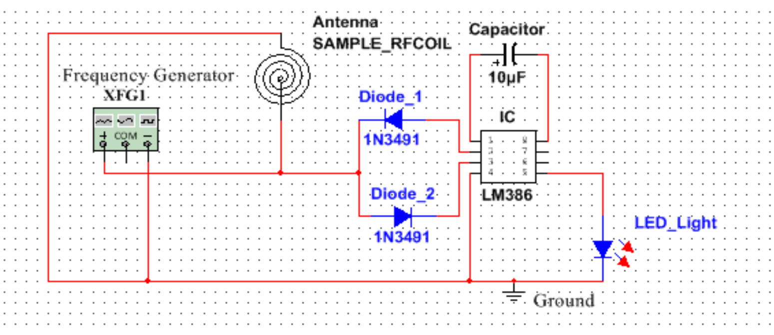


Figure 3.4: Circuit of electromagnetic radiation detection using diode 1N3491

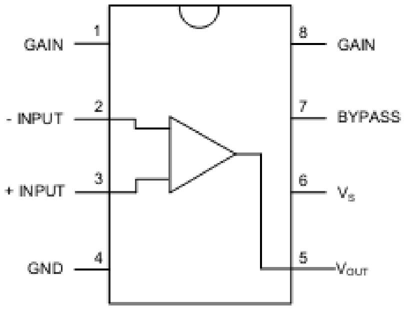


Figure 3.5: Pin configuration of LM386

The LM358 is used as a comparator. It has two inputs one is positive and another is negative equipped with a non-inverting input, an inverting input respectively. The fundamental function of this is to amplify the difference of two inputs. If input at positive is greater than at negative, this will amplify and output a positive signal; if negative is greater, it will output an amplified negative signal. 10μF capacitor is used for smooth output and fast response. LED light is attached at pin 5. When program run LED, light become visible. This indicates the presence of electromagnetic radiation. This radiation power can be measured by multimeter. In terms of current, power is P=VI, where V is voltage and I is the current. To find the value of current and voltage, the multimeter has to be connected in series and parallel respectively at output pin of IC. The value of power can be calculated by multiplying the values of current and voltage for a specific frequency.

3.8 VALIDATION TEST

Validation test is the method of forming the thesis are legally true or correct. It is the process to determine whether it satisfies specified requirements. It ensures that the thesis actually meets or fulfils the needs. For validation test the result of SAR and temperature change for different tissue is compare with other research paper. It must be noted in advance that it is identical hard to show a straight comparison between present paper and another research because it is not possible to direct measure the SAR and temperature increase in the skin, brain and other tissue. SAR and temperature values were calculated using real data, but in published work, calculations were performed using simulation software. Different parameters have been observed while comparing this value such as radiated power, distance, exposure time, dielectric properties, electric field strength etc.

Firstly, the published work data was collected. Then the same condition is applied to the newly discovered equation. Finally compare this value.

3.9 SUMMERY

This chapter presented the mathematical equation of SAR and temperature change for skin, fat, bone, brain and eye. This mathematical equation can be used for finding any kind of human tissue SAR value. Data calculation is performed by Microsoft excel and MATLAB. Also, design a circuit diagram that can detect the power of mobile phone electromagnetic radiation. Finally, compare the calculated data with published work.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

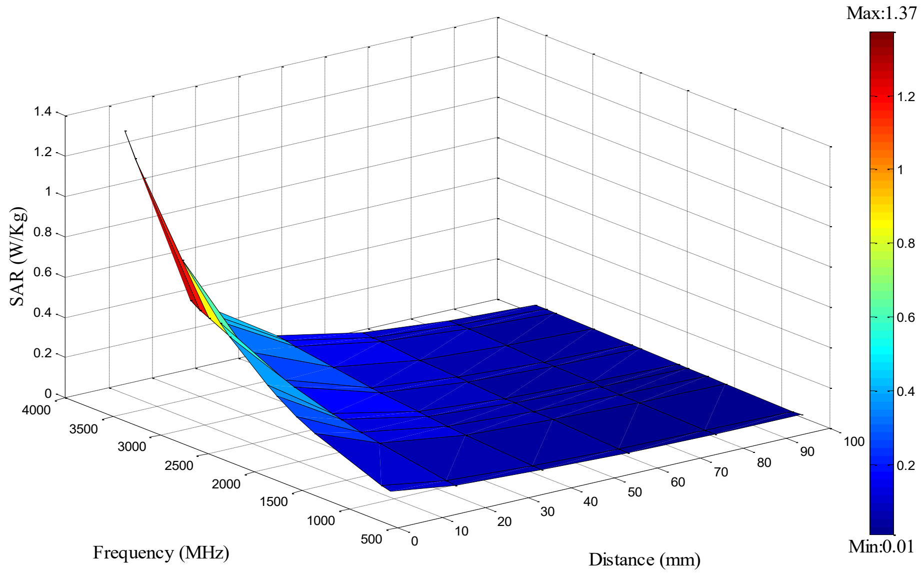
In this chapter, the results which obtained from methodology are presented and discussed. Firstly, present the specific absorption rate for different frequency and distance. Secondly, compare the specific absorption rate value between adult and child. Thirdly, shown the temperature value for near field distance. Fourthly, represent the power value which is obtained from simulation software. Finally, radiation effect and safety guidelines are discussed.

4.2 EFFECT OF FREQUENCY AND DISTANCE ON SAR

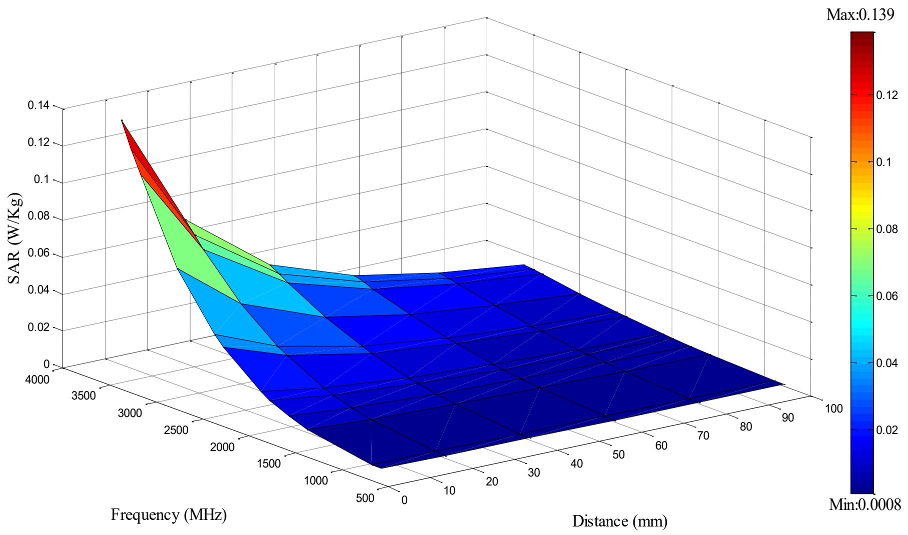
SAR variation is frequency dependent viewing that by increasing the dielectric values SAR value changes are not the same between the specific frequencies. The conductivity and relative permittivity of human head tissues such as skin, fat, bone, brain,muscel and eye depend on mobile generation. One kind of generation use one kind of frequency**.** There is a special significance when human head tissue is analyzed by their SAR value. The observations are made at 5 to 100 mm distances and 800MHz to 3600MHz frequencies within the skin, fat, bone, brain, muscle and eye at different depth. The calculations show, the specific absorption rate is maximum for brain. Here also apply actual radiated power for different generation. The calculated penetration depth is very low for brain so it provides high rate of SAR value and temperature. Skin and eye SAR value are also high for their high value of conductivity. The fat and bone values found are almost same.

4.2.1 For Power 0.125W

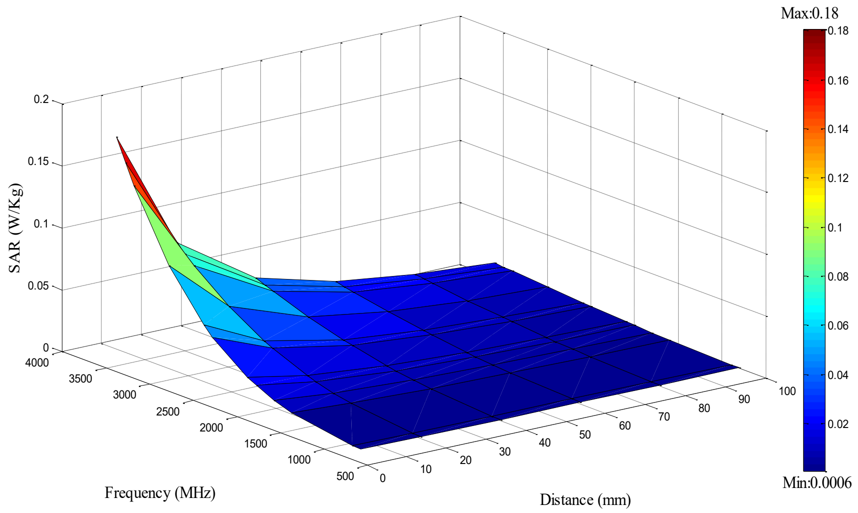
Radiated power can change the specific absorption rate. Figure 4.1 shown the computed SAR value of human tissue,which consist of skin, fat, bone ,brain, muscel and eye SAR value for different frequency and distance.



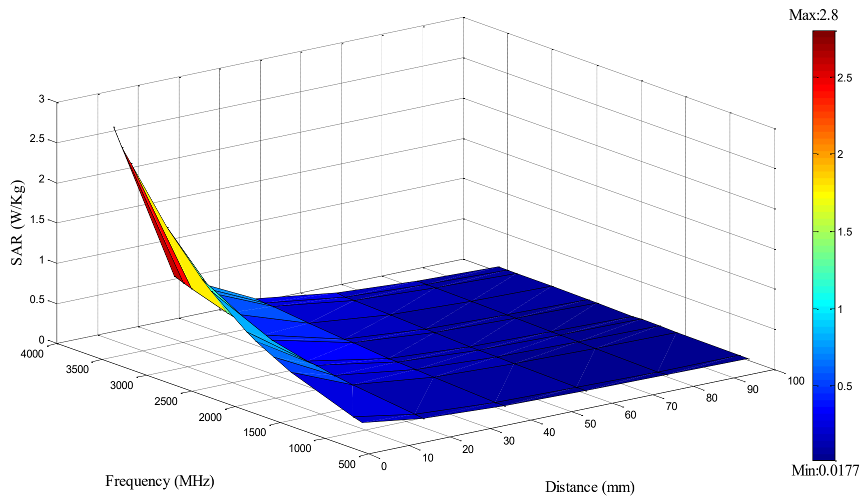
(a) For skin



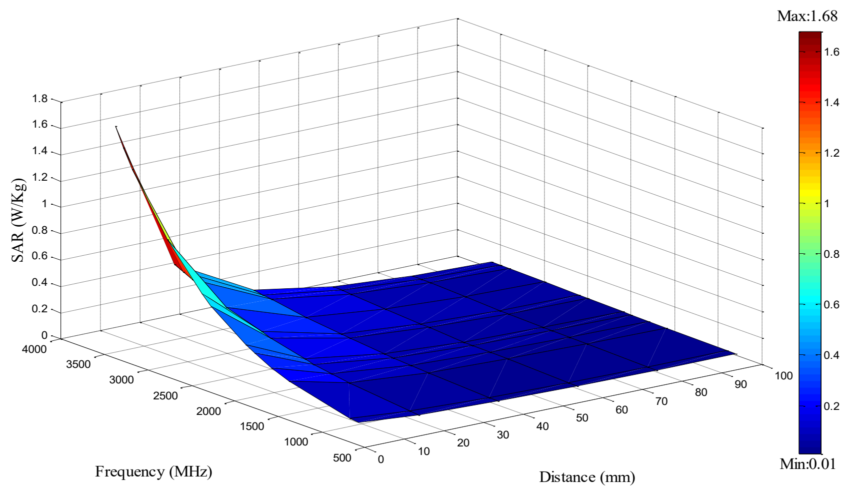
(b) For fat



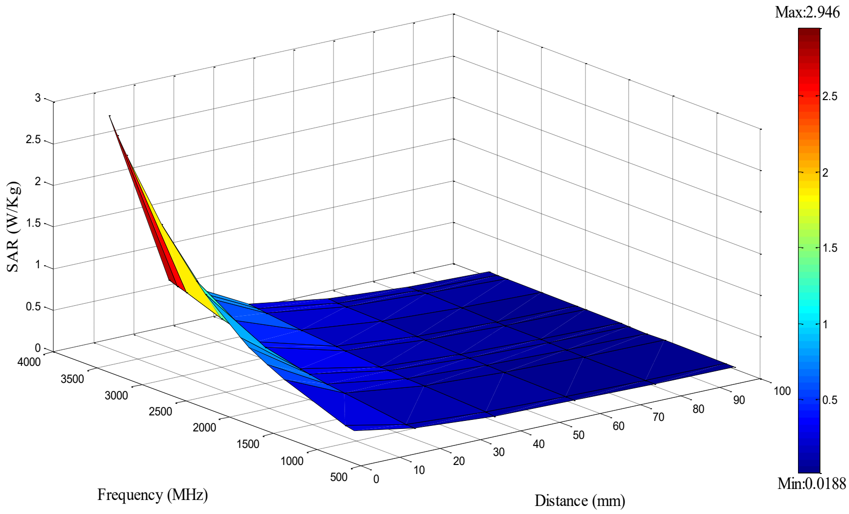
(c) For bone



(d) For brain



(e) For muscle



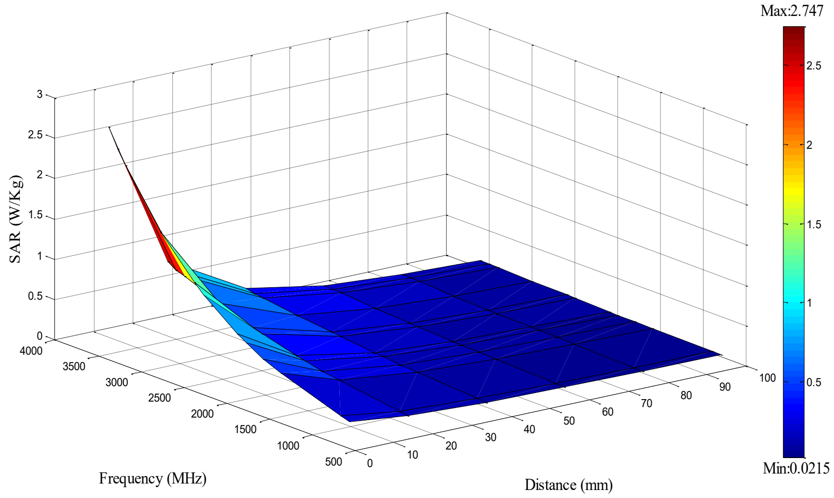
(f) For eye

Figure 4.1: Computed SAR for different distance and frequency with power(P)=0.125W

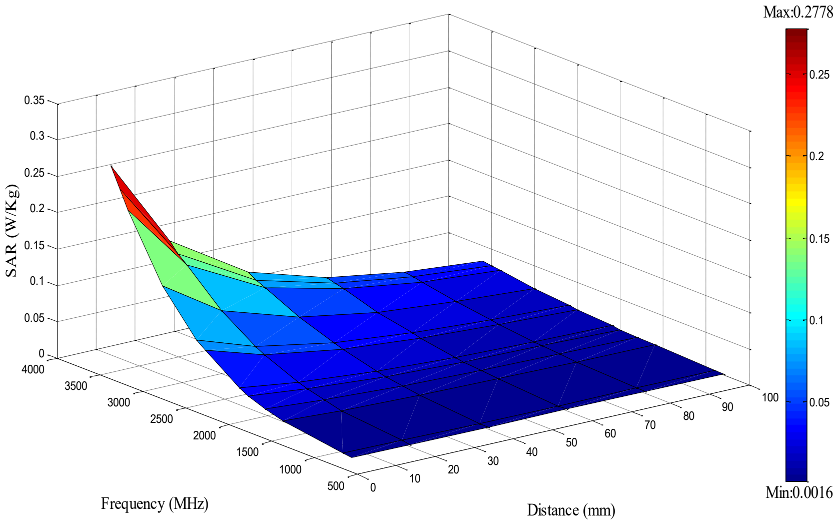
At frequency 3400MHz, 3500MHz ,3600 MHz (commonly use for 5G technology) the brain and the eye SAR cross the limit of ICNIRP 2W/Kg value when radiated power is 0.125W. At distance 5mm the SAR value of brian with 3400 MHz is 2.43W/Kg, 3500MHz is 2.59 W/Kg and 3600MHz is 2.80 W/Kg. For eye this value at 3400 MHz is 2.55 W/Kg, 3500 MHz is 2.74 W/Kg and 3600 MHz is 2.946 W/Kg. But the skin, fat and bone SAR value is below the ICNIRP limit. The brain and eye showed high value because of their low penetration depth. The calculated penetration depth value for brain is 0.012 m and eye is 0.011m which is low than other human tissue.

4.2.2 For Power 0.250 W

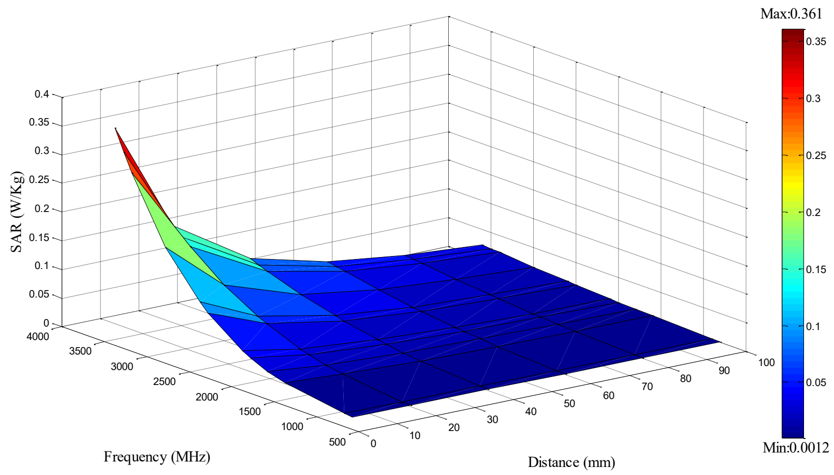
If the radiated power increase from 0.125 to 0.250W the value of specific absorption rate is also increase. But increse rate is not same for all tissue. Figure 4.2 shown that SAR value is increased when frequency is increased for skin, fat, bone ,brain, muscle and eye. At distance 5mm the skin,brain,muscle and the eye SAR values cross the limit of ICNIRP when frequencies are above 2600MHz. At distance 5mm the SAR value of skin with 3400 MHz is 2.35 W/Kg, 3500 MHz is 2.51 W/Kg, 3600 is 2.75 W/Kg. For brain this value at



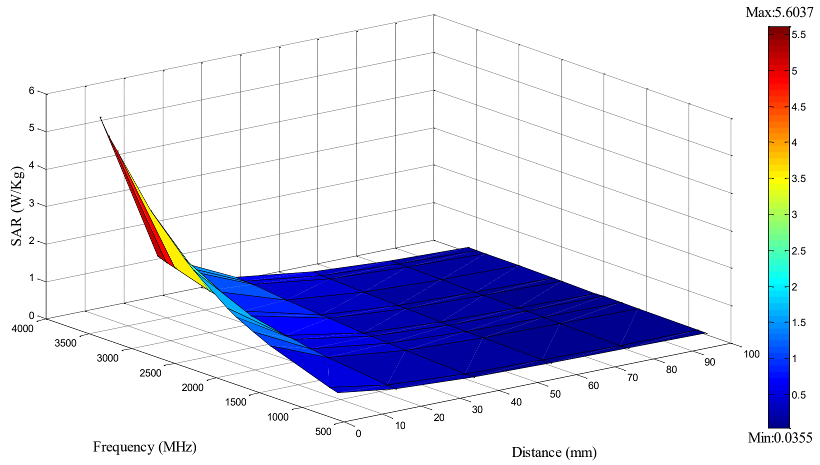
(a) For skin



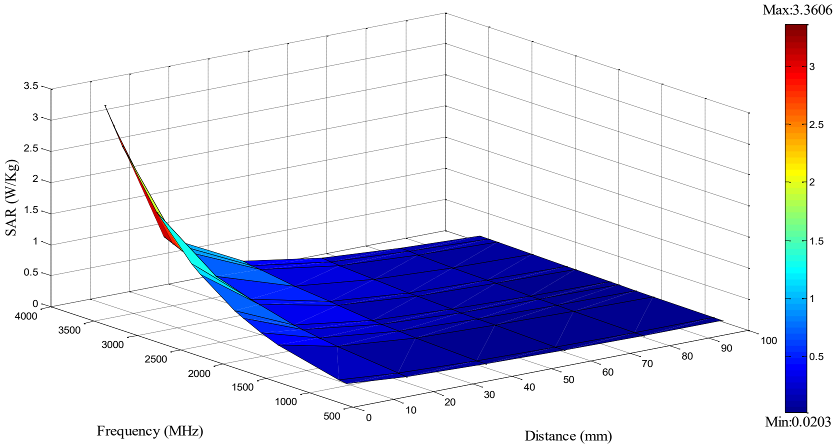
(b) For fat



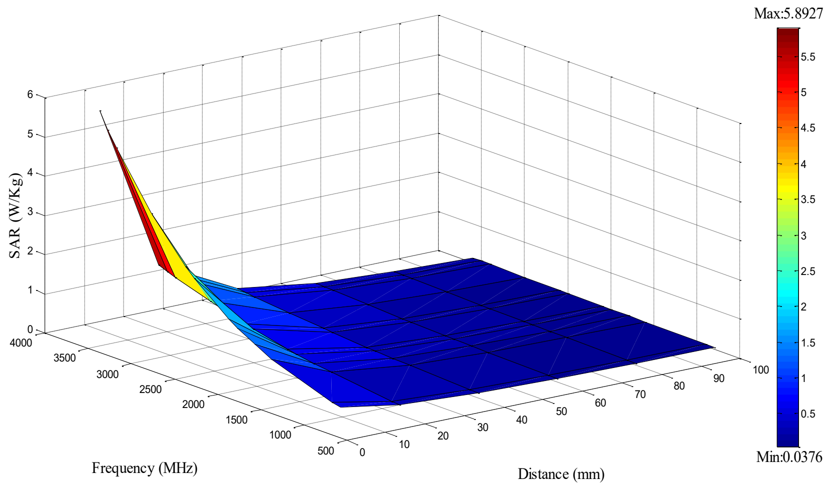
(c) For bone



(d) For brain



(e) For muscle



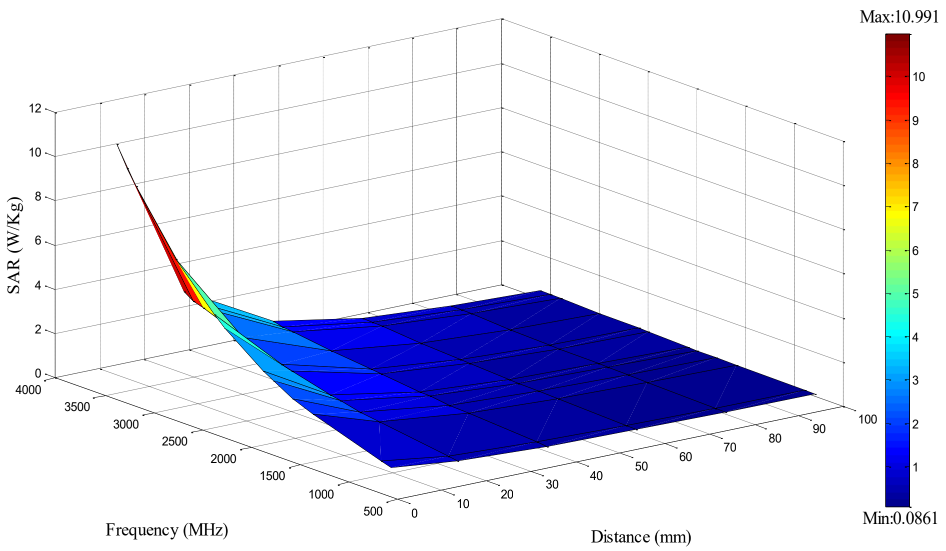
(f) For eye

Figure 4.2: Computed SAR for different distance and frequency with power(P)=0.250W

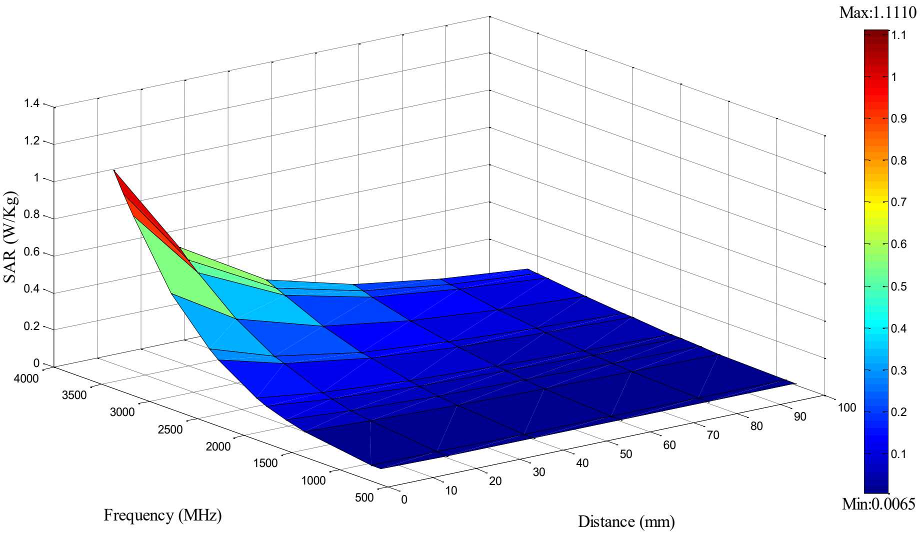
2500 MHz is 2.38 W/Kg, 2600 MHz is 2.60 W/Kg, 3000 MHz is 3.57 W/Kg, 3400 MHz is 4.86 W/Kg, 3500 MHz is 5.19 W/Kg, 3600 MHz is 5.60 W/Kg. For Muscel this value at 3400 MHz is 2.80 W/Kg, 3500 MHz is 3.08 W/Kg, 3600 MHz is 3.36 W/Kg. For Eye this value at 2500 MHz is 2.47 W/Kg, 2600 MHz is 2.69 W/Kg, 3000 MHz is 3.74 W/Kg, 3400 MHz is 5.10 W/Kg, 3500 MHz is 5.48 W/Kg, 3600 MHz is 5.89 W/Kg.This frequency is communly used for 4G and 5G technology. But the fat and bone SAR value is below the ICNIRP limit. Maximum SAR values is found for the brain. The skin , brain, muscel and eye showed high SAR vsalue because of their high conductivity and low relative permittivity value.

4.2.3 For Power 1W

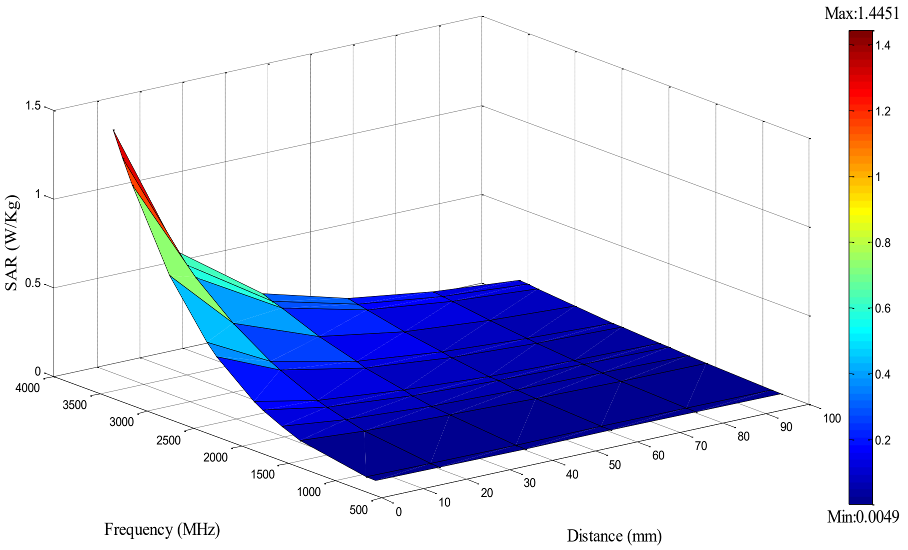
For radiated power 1W the skin,brain,muscel and the eye SAR values cross the limit of ICNIRP which shown in Figure 4.3. At distance 5mm the skin,brain,muscle and the eye SAR values cross the limit of ICNIRP when frequencies are above 1800MHz. This frequency is communly used for 3G, 4G and 5G technology. But the fat and bone SAR value is below the ICNIRP limit. This time maximum SAR values is found for the eye. The skin , brain, muscel and eye showed high SAR vsalue because of their high electric field strength. Due to more electric field strength more radiation is absorp by the tissue. But the fat and bone tissue has low penetration depth so it has low electric field strenght impact. The SAR value for fat and bone are low.



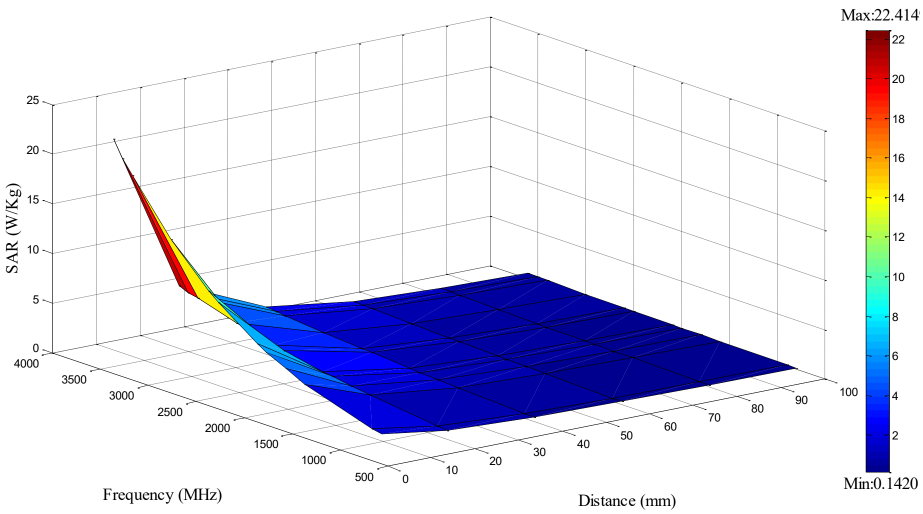
(a) For skin



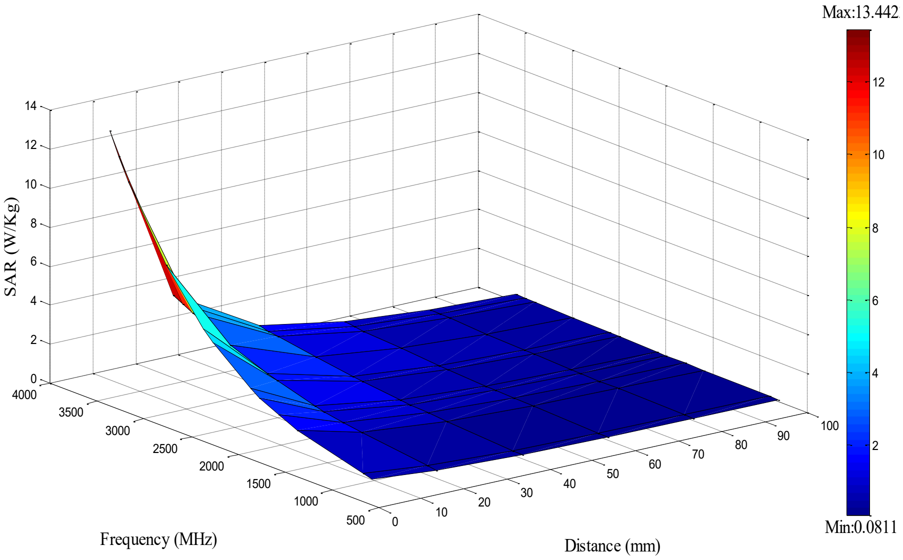
(b) For fat



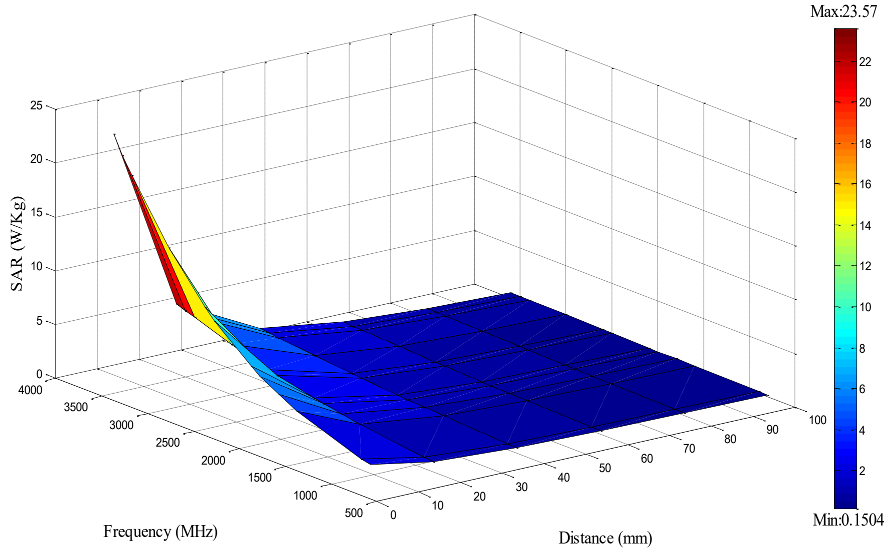
(c) For bone



(d) For brain



(e) For muscle

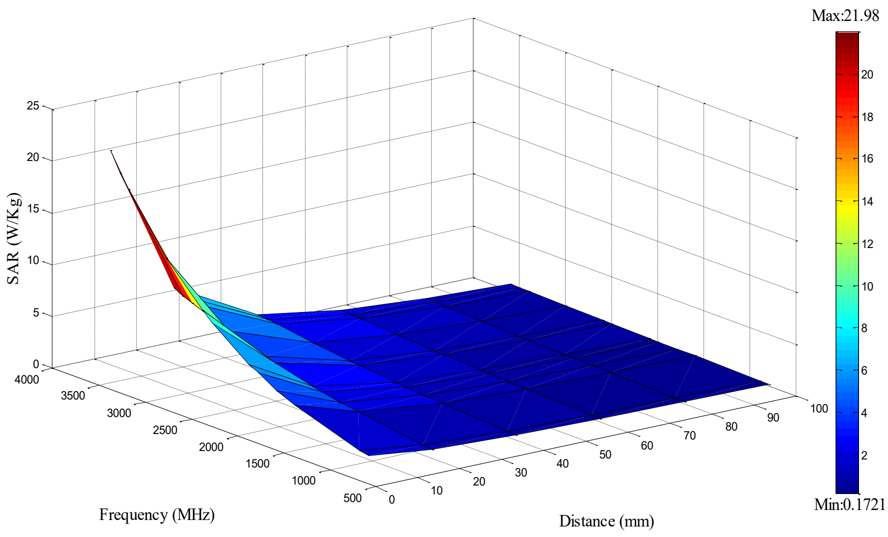


(f) For eye

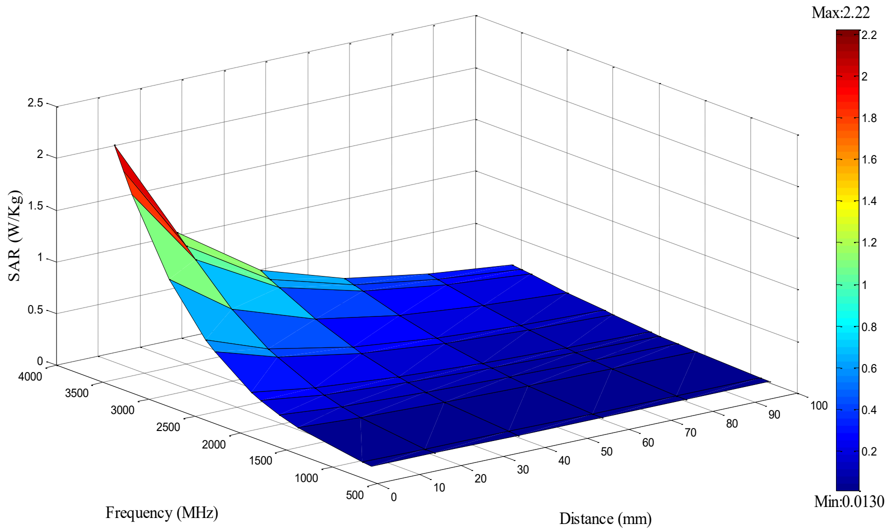
Figure 4.3: Computed SAR for different distance and frequency with power(P)=1W

4.2.4 For Power 2W

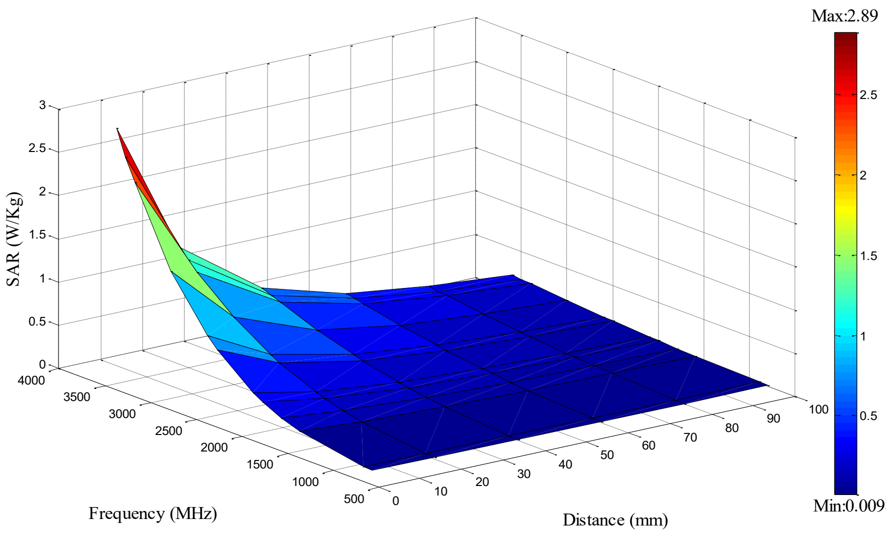
If the radiated power increse from 1 to 2W, the value of specific absorption rate is also increase. Figure 4.4 it is shown the value of the SAR for skin, fat, bone ,brain, muscel and eye. This time the frequencies are calculated from 800MHz to 3600MHz. At distance 5mm to 100mm the skin,brain,muscle and the eye SAR values cross the limit of ICNIRP



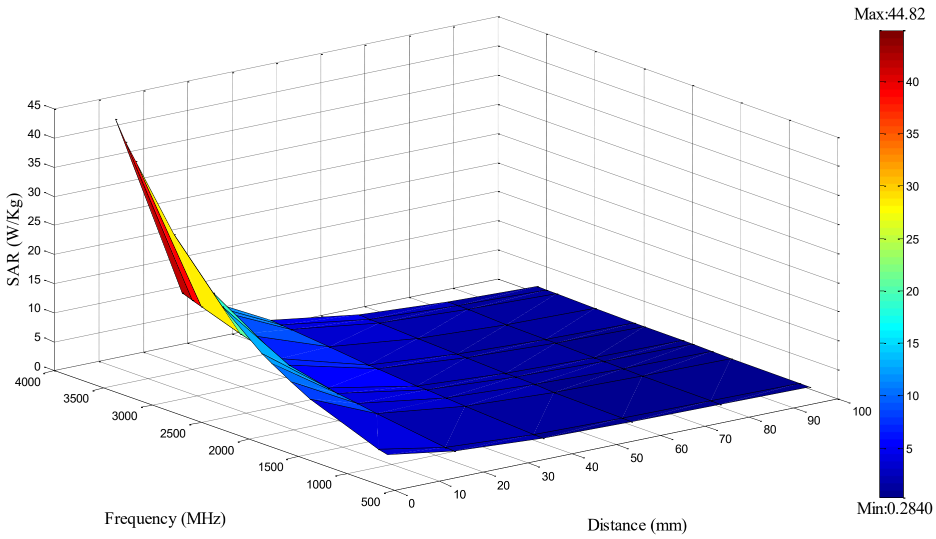
(a) For skin



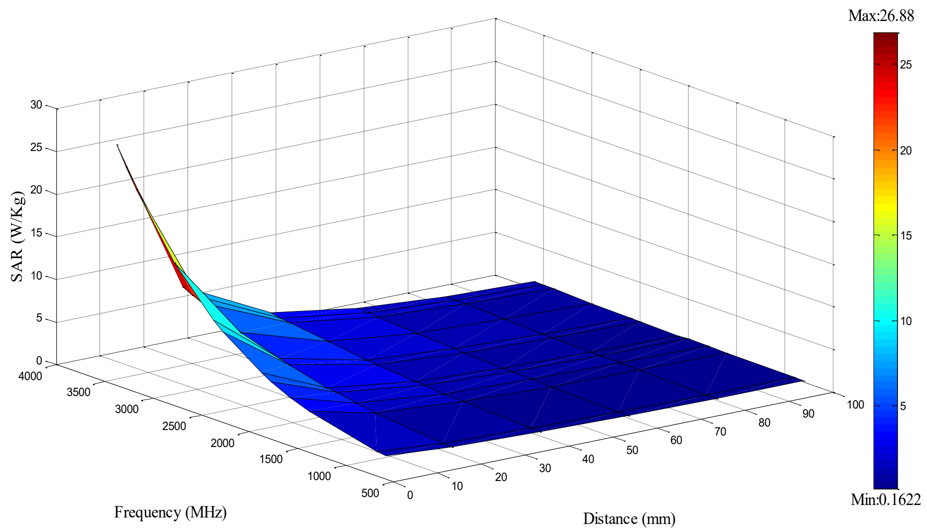
(b) For fat



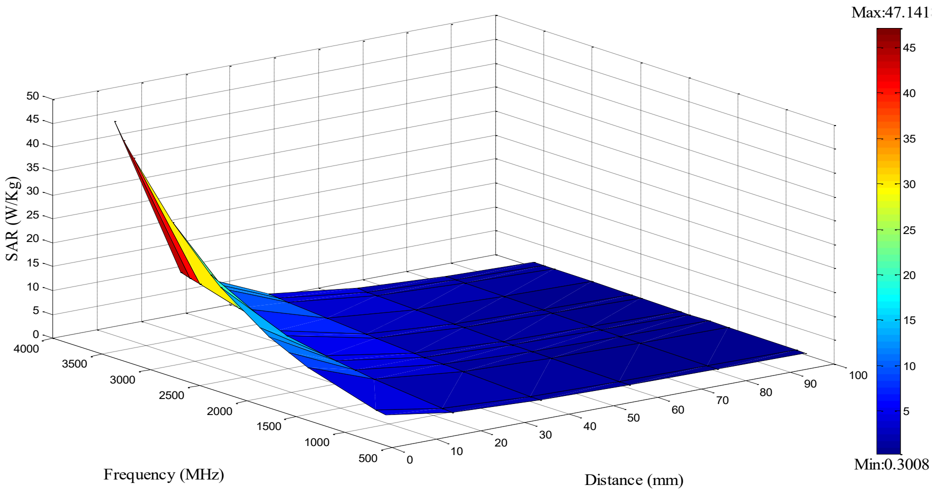
(c) For bone



(d) For brain



(e) For muscle



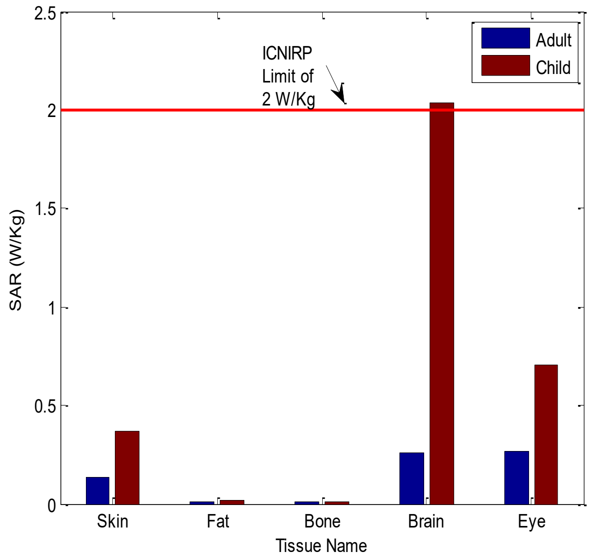
(f) For eye

Figure 4.4: Computed SAR for different distance and frequency with power(P)=2W

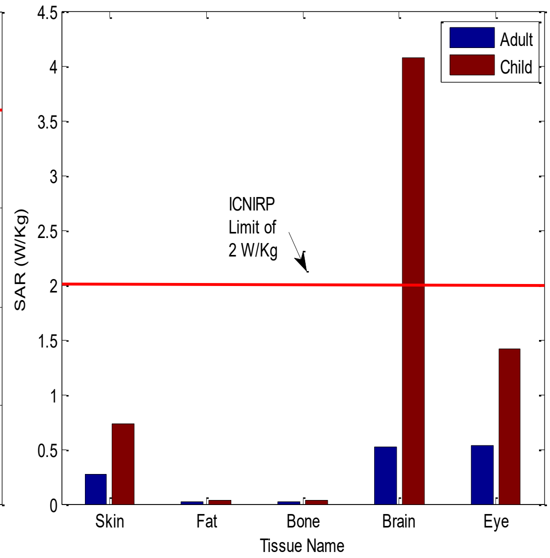
when frequencies are above 800MHz. This 2W radiated power is dnager for 2G, 3G,4G and 5G mobile technology. The skin ,fat,bone, brain, muscel and eye showed high SAR value because of their high radiated power and electri field strenght value. More penetration depth provides less damage to human tissue. The value of penetrated radiations increases with decrease in distance from human head and mobile phone. Thus, smaller penetration depth is better for human body.

4.3 COMPARISON OF SAR BETWEEN ADULT AND CHILD

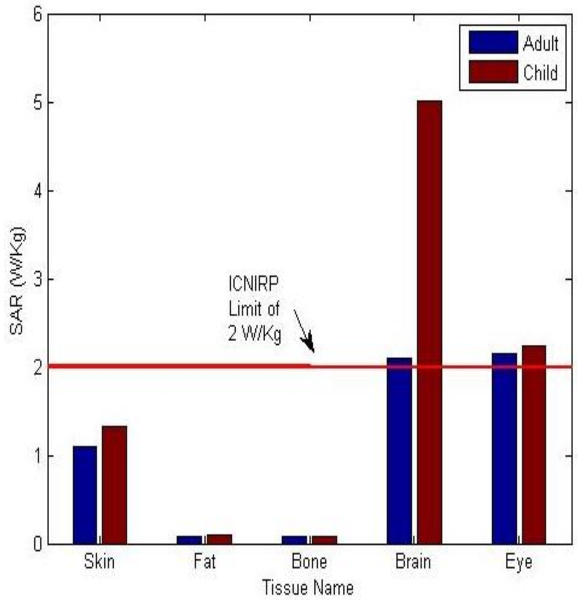
The rate of absorption in tissue increases as the distance decreases and the radiated power increases depending on their dielectric and thermal properties. The penetration depth of the electric field at the higher frequencies was smaller resulting in a stronger electric field in tissues that are near to the mobile phones. The peak SAR value for adult and child is found at brain for near field distance. The child head has a higher absorption rate of mobile phone radiation than the adult head. The highest value of the electric field is found at brain, eye and skin in child body. Figure 4.5 shown the comparison of SAR for adult and child for near field distance when the radiated power is 0.125,0.250,1 and 2W. The results specify that child head always has a higher absorption rate than the adult head because of their dielectric and thermal properties. The child brain SAR value is 2.03W/Kg when radiated power is 0.125W which is shown in Figure 4.5(a). When mobile phone radiated 0.250W power, the child brain and eye is affected more then adult. Child brain and eye SAR value is 4.06 W/Kg and 1.18 W/Kg this shown in Figure 4.5(b). But for the same power the adult tisse remain below the safty limit. From Figure 4.5(c) it is shown that the child brain SAR value is 5 W/Kg and adult is 2.11 W/Kg due to high electric field strength. Also child eye and skin tissue are cross the ICNIRP limit. For radiating power 2W the SAR value both for adult and child tissue such as skin ,brain and eye cross the ICNIRP limit. But the child tissue is more affected then adult tissue because of high conductivity and relative permittivity value which shown in Figure 4.5(d). This comparision shown that the child brain, eye and skin is more affected than adult tissue. The obtained results from the study also show that the children are more exposed and have a greater possibility of a serious adverse effect than the adult when exposed to mobile phone radiation. Children are possibly doughtier to radio frequency effects because of their developing nervous systems and immature immune systems.



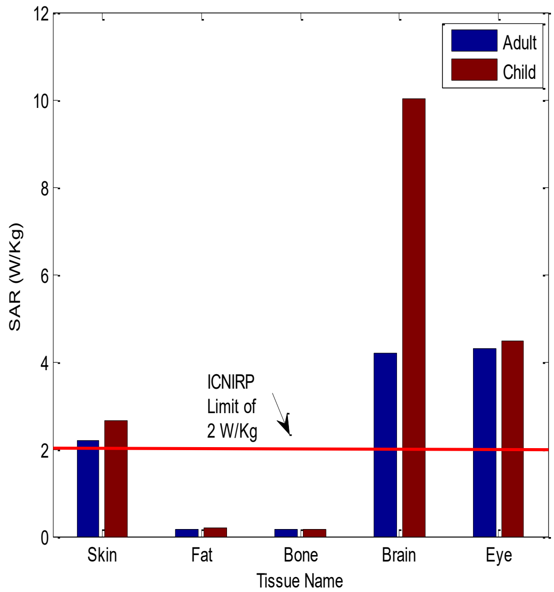
(a) At power=0.125W



(b) At power=0.250W



(c) At power=1W



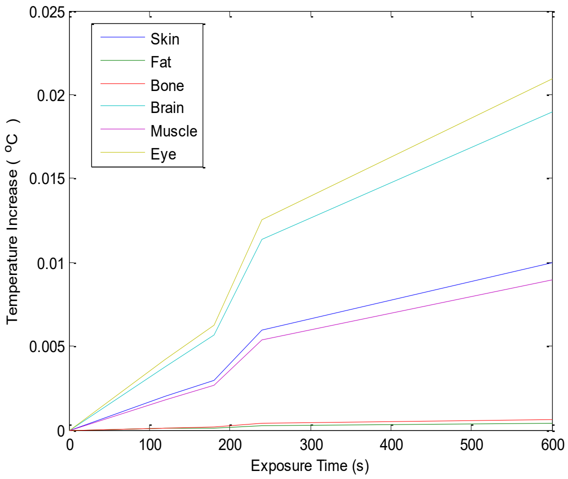
(d) At power=2W

Figure 4.5: Comparision of SAR in different human tissue for adult and child

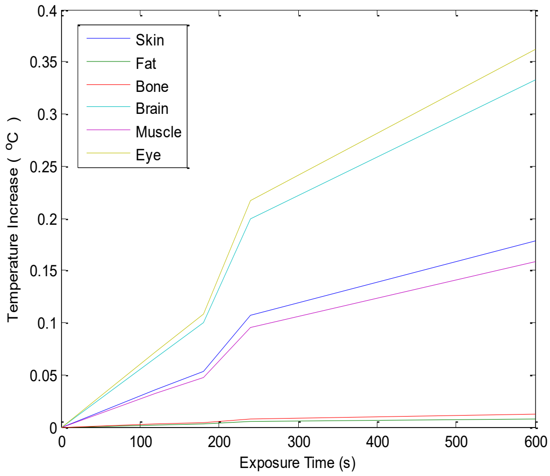
4.4 TEMPERATURE ANALYSIS ON HUMAN TISSUE

When using a mobile phone, most of the heating effect is found at the head in human body. Its temperature increases by many factors such as exposure time, heat capacity and

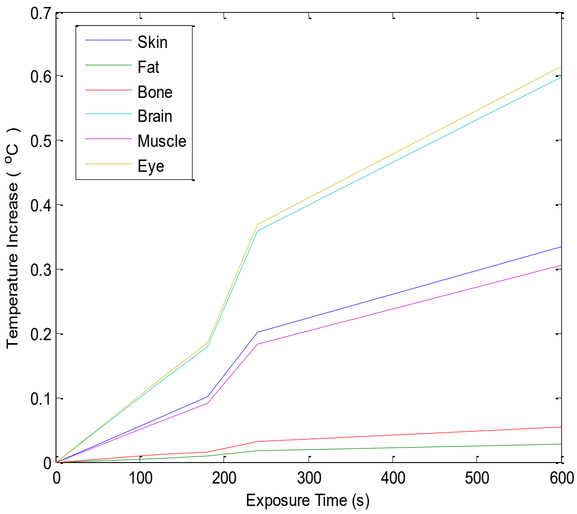
SAR value. The skin, brain and eye become more tempered than fat and bone which is shown in Figure 4.6.



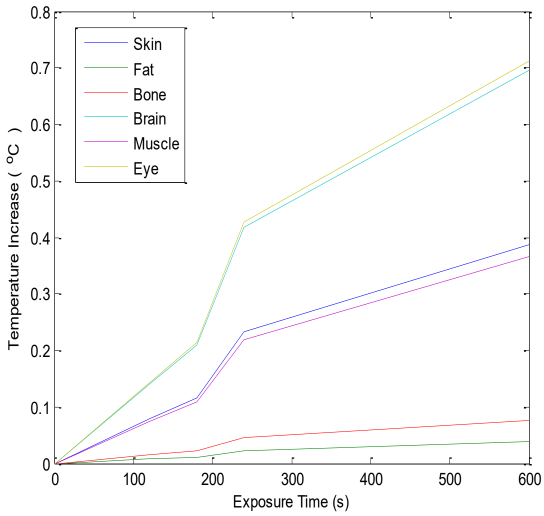
(a) For 800MHz



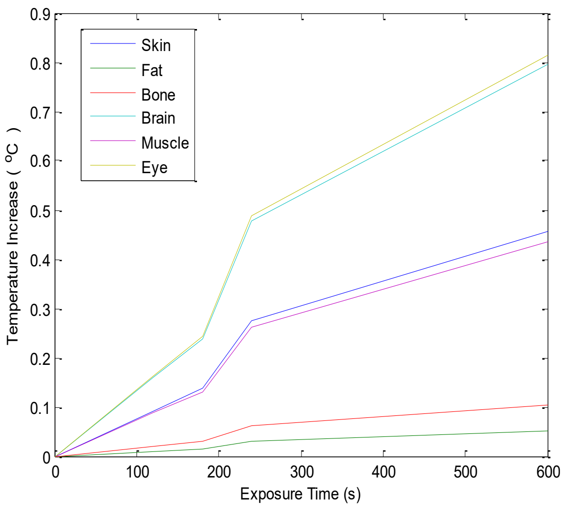
(b) For 900MHz



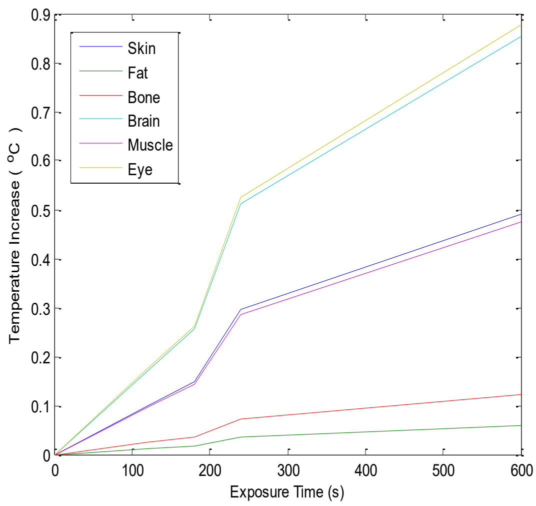
(c) For 1600MHz



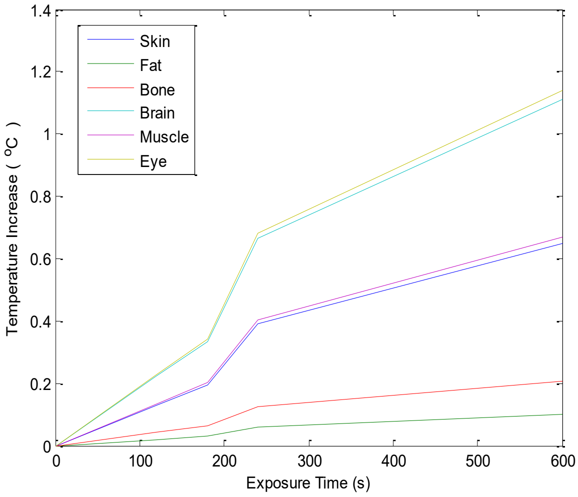
(d) For 1800MHz



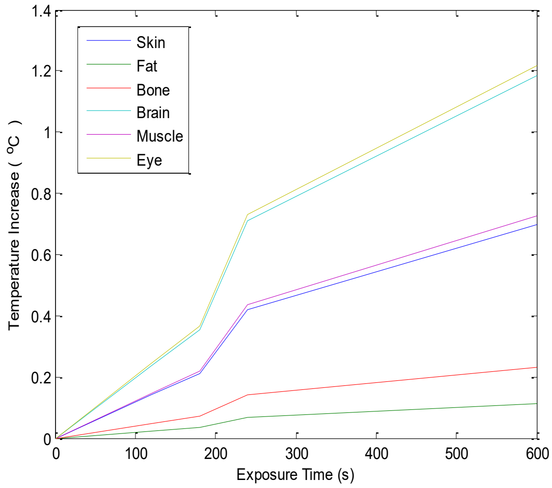
(e) For 2000MHz



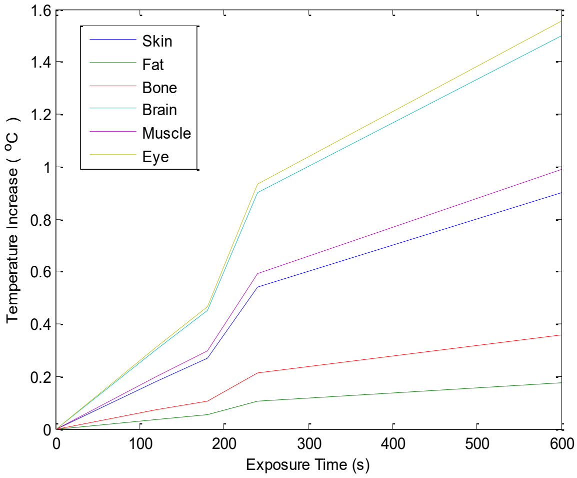
(f) For 2100MHz



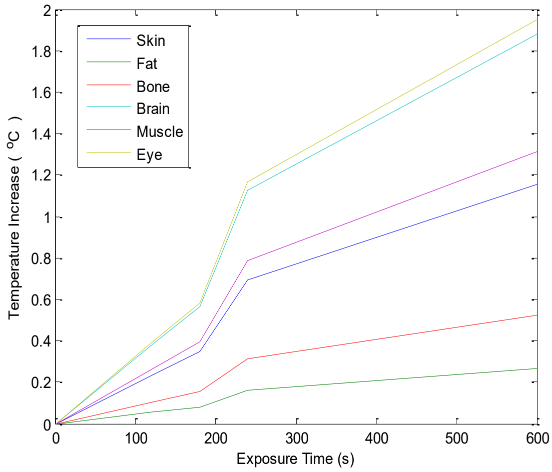
(g) For 2500MHz



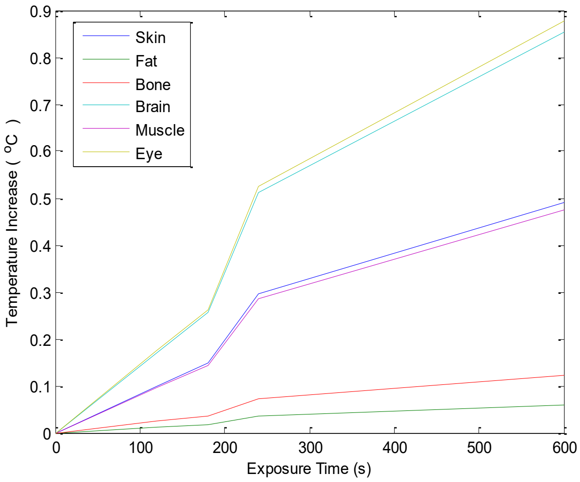
(h) For 2600MHz



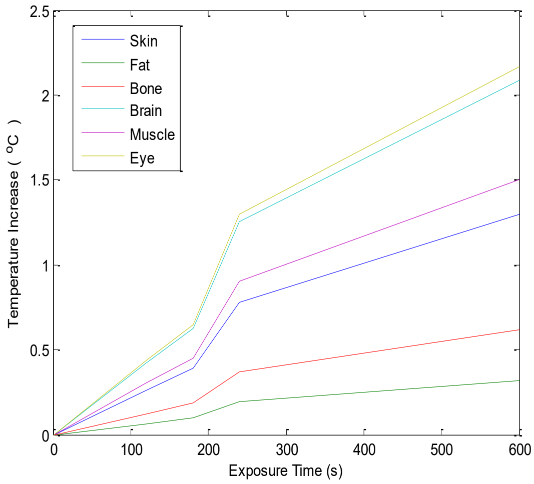
(i) For 3000MHz



(j) For 3400MHz



(k) For 3500MHz



(l) For 3600MHz

Figure 4.6: Change in temperature(°C) for different tissue with duration

For additional heat, this increased tissue temperature disposes of the brain's blood flow easily. When distance between mobile phone and tissue is decrees form 100mm to 5mm the temperature of tissues increases due to high value of SAR. After exposure time increases from 2 minute to 6 minute the temperature of tissues increases due to an inferior depth of penetration of the electric field and a higher SAR when the frequency is higher. Here, the temperature is calculated for near field distance such with radiated power 2 W. This temperature is calculated for fixed radiated value. If the value of radiated power decrease with increases in exposure time, then the value of temperature also decreases. It is also found that the eye temperature never exceeds 2.5°C, Muscle and skin 1.5°C, Brain 2°C, fat and bone 1°C. Obtained result shown that the temperature depends on various factors such as the size of the mass density of the tissue, electrical properties of the tissue and the distance between the mobile phone and human body etc. The brain, eye and skin tissues with mobile phone for 600 seconds increasing temperature more in the tissue as compare to the fat, bone and muscle.

4.5 POWER OBTAINED FROM SIMULATION

Mobile phone generation use different type of frequency for communication. In modern word the commonly uses technology are 2G,3G,4G and 5G. Table 4.1 and 4.2 shown the minimum and maximum radiated power for frequency 800MHz to 3600MHz. Maximum power obtained at 3600 MHz and minimum power obtained at 800MHz.

Table 4.1: Minimum radiated power for frequency 800MHz to 3600MHz

Frequency (MHz)	Voltage (mV)	Current (mA)	Power (W)
800	27.19	6.13	0.17
900	26.90	6.76	0.18
1600	26.10	12.79	0.33
1800	25.93	15.00	0.39
2000	25.88	17.29	0.45
2100	25.71	18.31	0.47
2500	24.19	25.17	0.61
2600	25.41	26.24	0.67
3000	25.23	28.75	0.73
3400	25.13	38.79	0.97
3500	25.12	35.74	0.90
3600	25.01	40.33	1.01

According to the simulated circuit the radiated power of mobile phone is increased when frequency is increased. But the value of current, voltage and power are found different for 3500 frequencies. This radiated power is as same as real power. That's why this paper consider power from 0.125 to 2 W.

Table 4.2: Maximum radiated power for frequency 800MHz to 3600MHz

Frequency (MHz)	Voltage (mV)	Current (mA)	Power(W)
800	30.22	9.88	0.30
900	37.50	10.60	0.40
1600	35.10	24.79	0.87
1800	35.49	27.85	0.99
2000	35.89	30.40	1.09
2100	36.11	30.99	1.12
2500	36.13	32.55	1.18
2600	36.59	32.95	1.21
3000	37.04	47.40	1.76
3400	37.29	50.50	1.88
3500	37.20	51.90	1.93
3600	37.28	52.88	1.97

4.6 OPTIMUM POWER AND DISTANCE FOR DIFFERENT GENERATION

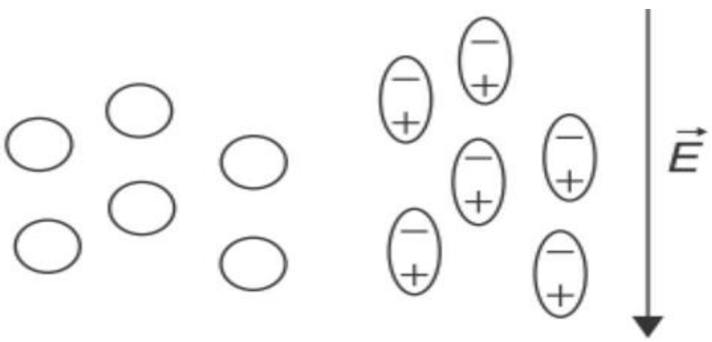
When mobile phone radiated maximum power, the value of SAR crosses the safety limit. Long term use has bad effect on human body. For the worst-case mobile phone radiated 2W. Different mobile generation use different frequency for their communication. So, it is necessary to know which power cannot be surpassed for different generations. Table 4.3 shown the safety distance with radiated power.

Table 4.3: Optimum radiated power for different frequency

Frequency (MHz)	Generation	Distance(mm)	Radiated Power (W)
900,800,1800	2G	0	Below 0.125
		5	Below 0.250
1900,2100	3G	0	Below 0.0625
		5	Below 0.250
2500,2600	4G	0	Below 0.0625
		5	Below 0.125
3400,3500,3600	5G	0	Below 0.0156
		5	Below 0.625

4.7 DISTINCT EFFECT OF RADIATION ON HUMAN BODY

A direct and clear effect for electromagnetic radiation findings is not so easy because there are many parameters. Human tissue is a heterogeneous material containing water, macromolecules, ions, dissolved organic molecules, and insoluble matter. The presence of ions plays an important role in the interaction with an electric field, providing means for ionic conduction and polarization effects. The dielectric materials of human tissue accompanied by the displacement of positive and negative charges under the influence of the applied electric fields, against the force of atomic and molecular attraction. Dielectric heating takes place due to this phenomenon. When a dielectric material of nonpolar molecules is exposed to the external electric field, the electrons move away from the nucleus by the amount of electric field applied to it. When the external field is removed, the electron comes back to their original state. The molecules displacement in human tissue for long time is harmful for the human tissue. By analysis the SAR and temperature value from above, the tissue absorbs the radiation and also change by temperature. Figure 4.10 shown the atoms situation for applied electric field. At the highest exposure levels for a long-term using a mobile phone increase the head tumor risk. Because brain tissue provides high SAR and temperature value. It also increases the risk of brain gliomas and acoustic neuro mass for long time uses.



(a) (b)

Figure 4.7: (a) Atoms when no external electric field applied (b) electric diploes induced as the externally applied electric field distorts the electron cloud

Tumor risk arise for using mobile phone more than 15 years [34-40]. The insect's reproductive capacity and apoptotic cell death occur when mobile phone electromagnetic radiation is applied to drosophila melanogaster for 6-8 days [41]. Mobile phone radiation alters the pupal development but no further impairment has manifested in adult hood when queen larvae and pupae were kept with a mobile phone attached to the grafting frame for 14 days [42]. Heart rate variability observed when mobile phone is placed near the chest [43]. DNA damage were shown for mobile phone electromagnetic radiation by fenton reaction analysis of cell [44]. It also induces oxidative and nitrosative stress, which affects the reproductive performance of female mice [45]. Children are possibly doughtier to radio frequency effects because of their developing nervous systems and immature immune systems. The mobile phone electromagnetic radiation affects the alpha rhythm of human waking EEG [46-47].

4.8 VALIDATION

The value of SAR for present and published paper are not totally same for some tissue due to variation of dielectric parameter and penetration depth value of brain, skin, fat and bone. Table 4.4 shown the SAR comparison of present and published data.

Table 4.4: Comparison of SAR between present and published work

Reference	Frequency	Tissue Name	Present Work SAR(W/Kg)	Published Work SAR (W/Kg)
[48]	2600 MHz	Skin	0.80	0.68
		Brain	0.07	0.66
		Eye	0.44	0.24
[49]	900 MHz	Eye	1.50	1.40
		Brain	1.40	1.01
[50]	900 MHz	Skin	0.71	0.82
		Fat	0.017	0.12
		Bone	0.015	0.15
		Brain	0.16	0.20
	1800MHz	Skin	1.65	1.20
		Fat	0.09	0.20
		Bone	0.11	0.14
		Brain	1.53	0.30

Table 4.5 shown the comparison of present and published calculated data for temperature change.

Table 4.5: Comparison of temperature change between present and published work

Reference	Frequency	Tissue Name	Present Work (°C)	Published Work(°C)
[51]	900 MHz	Eye	0.139	0.132
		Brain	0.15	0.10
[52]	900 MHz	Skin	4.50	0.19
		Fat	0.14	0.18
		Bone	0.22	0.16

Present and published paper value for temperature is almost same at fat, bone, eye and brain but difference at skin due to variation of heat capacity and SAR value of tissue.

4.9 PROCESS TO REDUCE RADIATION

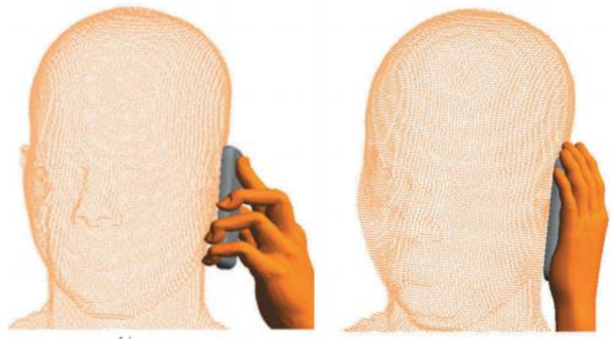
In this paepr two techniqe are described for reducing the electromagnatic raditaion from mobile phone. One is atachment of material sheilds into the mobile phone antenna and another is change the position of the finger while speaking.

4.9.1 Material Shields

The radiation from the mobile phones can be reduced using a material shield. This sheild help to decrease the value of SAR. However, this shield may afects the performance of the mobile phone antenna. Proper shield material has to be selected, which reduces the radiation with maintaining a good quality of signal transformation. Conductors material degrades the performance of the mobile phone antenna due to its high conductivity. Insulators shield do not absorb any radiation due to zero conductivity.In mobile communication the conductivity between 0.1 to 3 S/m is preferable for good sheilds. Aluminium, copper and germanium sheilds can be used for reducing the antenna radiation. Germanium provide better result for reducing radiation [53].

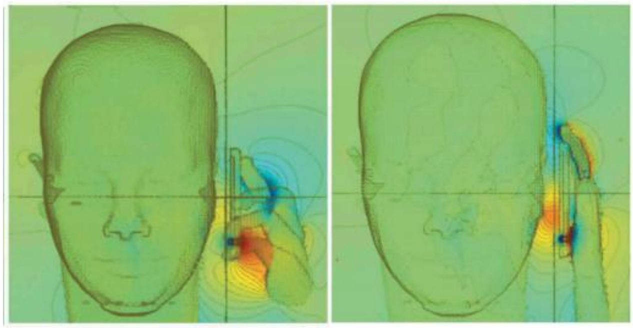
4.9.2 Position of Finger

In mobile communication system the free space between mobile phone and base station is preferable for good connection.The human head and hand being in the near-field zone of a mobile phone antenna.This create a problem in free space antenna matching. When the signal strength at the base station drops the automatic gain control (AGC) increases power. In the case when the phone is covered by the palm (hand 2) worse matching was observed both 900 MHz and 1900 MHz, compared to the case, when the phone was held by fingers (hand 1) [54]. These phenomena are illustrated in Figures 4.8 and 4.9. As a result, The hand holding the mobile communication device absorbs a part of the radiated energy, causing the increase of total radiated power for sustaining the required signal strength at the base station, as a result, the peak SAR values in the human head become significantly higher.So, the position of finger is important factor for mobile calling.



a) b)

Figure 4.8: Mobile position (a) with hand 1, and (b) with hand 2



a) b)

Figure 4.9: Human head and antenna distribution at hand model 900MHz, (a) with hand 1, and (b) with hand 2

4.10 SAFETY GUIDELINES OF MOBILE PHONE

Appropriate suggestion is attached below for stay safe from this electromagnetic radiation.

- Only use mobile phone for short duration this must be less than 4 minutes. Because after 4 minutes the tissue temperature is increasing highly.
- At the beginning of call maximum power is radiated. So, it is suggested to keep mobile away from head and ear while picking up a mobile call.
- Metal object and water are good conductors of electromagnetic signals. So, it is better to avoid mobile phone when wearing metal framed glasses or user hair is wet.
- Avoid using more than 4 minutes from one side of ear, simultaneity change after 4 minutes. By changing the ear side, the thermal effect may be reduced form this radiation.
- Wire headphone is recommended to reduce the exposure to radio frequency radiation in the head. Because more distance between head and mobile antenna generates less SAR value and temperature.
- Avoid using your mobile phone in places like a bus which are crowded. At moving time, the radiated power increase for good connection establishment.
- Avoid using mobile phone when the communication signal is weak as they transmit more power at that time.
- Keypad portion of mobile phone should be kept towards the body. Because the antenna is mostly placed at the back of the mobile phone.
- Child bodies has lees immunity so avoid giving mobile devices to children.

4.11 SUMMERY

Results obtained from this analysis shown that SAR and temperature value is maximum when power and exposure time is high with minimum distance. Also, comparisons of the absorption of mobile phone radiation are calculated between an adult and a 10-year-old child head model, for the brain and eye it provides high SAR value than adult. The penetration depth is maximum for fat and bone. Factors that can affect the extent of radiation exposure of mobile phone users can be the duration of use, the distance between mobile phone and human head, the amount of mobile phone traffic, the generation of the phone. Radiation energy increases when the frequency value increases. Here also design a mobile phone radiation detection circuit. It converts RF frequency waves to little current to flash a LED. It can detect radiation by using the load (LED) of this circuit. At the same levels of radiated power, SAR levels in the fat and bone are less than the safety limit recommendations, except in skin, brain, muscle, eye tissues.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

This chapter describes the conclusion and future research scope of this work. First the overall summary of this thesis work is presented in the conclusion section. Then the potential future research directions are provided in future research scope section.

5.2 CONCLUSION

A detailed analysis has been done to study the harmful effect of non-ionizing radiations emitted from the mobile phones on human body. The specific absorption rate of various mobile phones and the thermal effect of the radiations on the tissue is calculated in terms of penetration depth. So, it indicates that the SAR values decrease with increase the spacing between antenna and human head. There is an inversely proportional relationship between SAR and the distance between the body model and the excitation source. It is directly proportional to the conductivity in the radiated tissue, intensity of the induced electric field and inversely proportional to the density of tissue element. SAR values for higher frequency band are higher when the distance is minimal, which recommends us to avoid use of higher frequency band in the close vicinity of the user. Short term exposure effect also been observed for different skin, brain and eye tissues. Transmission power is higher when the mobile phone is used at the area with very low field strength of received signals. However, due to the growing use of mobile phones with longer confrontations period shown high risk in human health and resulting in a cumulative effect. Therefore, the extended use of mobile phones should be reduced to avoid any unwanted health hazards from EM waves. On the basis of above findings, following conclusions are drawn:

a) In all cases of exposure, the highest SAR and temperature in the human head occurred near the surface at higher frequency. This high value affects the human tissue and arise unwanted hazards because of ions displacement in human tissue.
b) Generally Bangladeshi people use 2G,3G,4G mobile phone. Long term use of this phone with high radiated power such as greater than 0.125W and distance less than 20 mm is harmful.
c) Tissue absorption rate in head tissue depend on the ability of the tissue to conductivity, relative permittivity, and the density in addition to radio frequency and source power.
d) For lower frequency the SAR value is maximum for eye tissue and for higher frequency the SAR is maximum for brain.
e) It is observed that when the radiated power is below 0.125W with 5mm distance the SAR and temperature value is remain low from the international standard value. But for higher radiated power from 0.125 W, cross the international standard value.
f) It is recommended according to this analysis that the distance between mobile phone and human head should be greater than or equal 20 mm to avoid high pick SAR and reliable performances.
g) Child absorption rate for brain and skin are more than the adult tissue due to their higher sensitivity tissue.

5.3 FUTURE WORK

International mobile telecommunication service is an interesting and fast-moving area of academic research. As stated at the beginning of this thesis, the telecommunication industry of Bangladesh is rapidly moving towards a crucial point. A lot of opportunities will be open for telecom operators in Bangladesh. Our future work is to provide a new methodology and algorithms establishment for minimization of radiation exposure from mobile phones and base stations. That will help for strategy formulation for the successful adoption of 4G and 5G technology.

REFERENCES

[1] Mat, D. A. A. 2010. "Visualization and Analytical Measurement of Electromagnetic Radiation from Handheld Mobile Phones, Second International Conference on Computer Engineering and Applications. Bali Island.**58** (3): 246-250.

[2] Rosenworcel, J.2012.Specific Absorption Rate (SAR) for Cellular Telephones, Federal Communications Commission, https://www.fcc.gov/general/specific-absorption-rate-sar-cellular-telephones#:~:text=Any%20cell%20phone%20at%20or,(1.6%20W%2Fkg), Accessed 25 June 2020.

[3] Fuglsang,N.2020.Harmful mobile phone radiation. European Union. https://www.europarl.europa.eu/doceo/document/E-9-2020 002425_EN.html#:~:text=In%20the%20EU%2C%20a%20SAR,US%20is%201.6%20 W%2Fkg. Accessed 25 June 2020.

[4] Zhao, K., Zhang, S., Ying, Z. and Bolin, T. (2013). SAR Study of Different MIMO Antenna Designs for LTE Application in Smart Mobile Phones. IEEE Transactions on Antennas and Propagation. **61**(6): doi- 10.1109/TAP.2013.2250239.

[5] Takei, R., Nagaoka, T., Saito, K. and Watanabe, S. 2017.SAR Variation Due to Exposure from a Smartphone Held at Various Positions Near the Torso. IEEE Transactions on Electromagnetic Compatibility. IEEE Transactions on Electromagnetic Compatibility. **59** (2):747-753.

[6] Bhargava, D., Leeprechanon, N., Rattanadecho, P., Wessapan, T. 2019. Specific absorption rate and temperature elevation in the human head due to overexposure to mobile phone radiation with different usage patterns, International Journal of Heat and Mass Transfer. **130**: 1178–1188.

[7] Alistar, B.D., Salceanu, A. and Lupuleasa, G. 2014. Approach on Simulating and Measuring the SAR, International Conference and Exposition on Electrical and Power Engineering.

[8] Zhang, H. (2018). Electromagnetic-Thermal Analysis of Human Head Exposed to Cell Phones with the Consideration of Radiative Cooling. IEEE Antennas and Wireless Propagation Letters.**17(**9):1584-1587.

[9] Ahmed, A. M. 2018. Specific Absorption Rate (SAR) Simulated for Square Patch Antenna of Head Tissues. Engineering and Technology Journal. **36**(5):509-513.

[10] Wessapan, T. and Rattanadecho, P.2013. Specific absorption rate and temperature increase in the human eye due to electromagnetic fields exposure at different frequencies. International Journal of Heat and Mass Transfer, **64**:426-435.

[11] Christopher, B., Khandaker, M.U. , and Jojo, P.J. 2020. Empirical study on specific absorption rate of head tissues due to induced heating of 4G cell phone radiation. Radiation Physics and Chemistry **178**: 190-196.

[12] Wessapan,T., Srisawatdhisukul, S. and Rattanadecho,P.2012. Specific absorption rate and temperature distributions in human head subjected to mobile phone radiation at different frequencies, International Journal of Heat and Mass Transfer **55**: 347–359.

[13] Poljak, D., Cvetkovic,M. Dodig,H. and Peratta, A. 2017.Electromagnetic - Thermal Analysis for Human Exposure to High Frequency Radiation. International Journal of Design and Nature and Ecodynamics. **12**(1): 55-67.

[14] Sabbah, A.I. , Dib, N.I. and Nimr, M.A. 2011.Evaluation of specific absorption rate and temperature elevation in a multi-layered human head model exposed to radio frequency radiation using the finite-difference time domain method. IET Microwaves Antennas & Propagation **5**(9):1073 – 1080.

[15] Stankovicl, V. , Jovanovic D. , Cvetkovic, N. and Markovic, V. 2015. Thermal Effects on Human Head from Mobile Phones.2015 12th International Conference on Telecommunication in Modern Satellite, Cable and Broadcasting Services (TELSIKS).205-208.

[16] Bhat, M.A. and Kumar,V. 2015.Change in Temperature of Skin, Blood, Muscle and Bone Tissues Due to Mobile Phone Radiations at Frequencies 800, 900, 1800 and 2450 MHz.American Journal of Engineering and Applied Science. **8**(3): 390-398.

[17] Wessapan, T., and Rattanadecho, P. 2012. Specific Absorption Rate and Temperature Increase in Human Eye Subjected to Electromagnetic Fields at 900 MHz. Journal of Heat Transfer. **134**(9): 91-101.

[18] Keshvari,J. and Keshvari, R. 2006.The effect of increase in dielectric values on specific absorption rate (SAR) in eye and head tissues following 900, 1800 and 2450 MHz radio frequency (RF) exposure. Physics in Medicine & Biology. **51**(6):1463-1477.

[19] D. Wu, S. Shamsi, J. Chen and W. Kainz.2006. Evaluations of Specific Absorption Rate and Temperature Increase Within Pregnant Female Models in Magnetic Resonance Imaging Birdcage Coils. IEEE Transactions on Microwave Theory and Techniques.**54(**12):4472-4478.

[20] Kaburcuk, F.2019.Effects of a brain tumor in a dispersive human head on SAR and temperature rise distributions due to RF sources at 4G and 5G frequencies. Electromagnetic Biology and Medicine.**38**(2):168-176.

[21] Ezequiel, I., Espinosa, R., and Roberto L. M., 2018.Analysis of SAR distribution in a heterogeneous and homogenous head model at 2.4 GHz using the FDTD method" , Microwave and Optical Technology Letters, **60**(6):1323-1331.

[22] Priyadarshini, S.J. and Hemanth, D.J.2017. Investigation and reduction methods of specific absorption rate for biomedical applications: A survey. International Journal of RF and Microwave Computer-Aided Engineering. **28**(3).211-223.

[23] Karli, R., Ammor, H. and Tehzaz,J.2014. Dosimetry in the human head for two types of mobile phone antennas at GSM frequencies. Central European Journal of Engineering.**4**:39-46.

[24] Khalatbari, S., Sardari, D., Mirzaee, A.A. and Sadafi, H.A. 2006. Calculating SAR in Two Models of the Human Head Exposed to Mobile Phones Radiations at 900 and 1800 MHz. Electromagnetics Research Symposium. **2**(1): 104-109.

[25] Hossain,M.I., Faruque,M.R.I. and Islam, M.T. 2015.Investigation of hand impact on PIFA performances and SAR in human head, Journal of Applied Research and Technology. **13**: 447-453.

[26] Dutta, P.K., Jayasree, P.V.Y. and Baba, V.S.S.N.S.2016. SAR reduction in the modelled human head for the mobile phone using different material shields. Human-centric Computing and Information Science.**6**(3):1-22.

[27] Khurana, V.G., Teo, C., Kundi, M., Hardell, L. and Carlberg, M.2009. Cell phones and brain tumors: a review including the long-term epidemiologic data. Surgical Neurology. **72**(3):205-14.

[28] Douglas, M. and Kainz, W. 2017. IEC/IEEE International Standard – Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz – Part 1: General requirements for using the finite-difference time-domain (FDTD) method for SAR calculations. IEEE.1-86.

[29] Sallomi, A.H.2012. A Theoretical Approach for SAR Calculation in Human Head Exposed to RF. Journal of Engineering and Development. **16**(4):304-313.

[30] Ellingson, S.W. 2018. Engineering Libre Texts. (Online). https://eng.libretexts.org/Bookshelves/Electrical_Engineering/Electro-Optics/Book%3A_Electromagnetics_I_(Ellingson)/10%3A_Appendices/10.02%3A_Permeability_of_Some_Common_Materials. 5 June 2020.

[31] Seybold, J.S. 2005. Introduction to RF Propagation. First Edition. United States of America: John Wiley & Sons Inc.5-25.

[32] Kuster,N., Capstik,M. and Neufeld, E.1999.Tissue Properties. IT'IS foundation. (Online) https://itis.swiss/virtual-population/tissue-properties/database/database-summary. Accessed 20 June 2020.

[33] Templeton, R. 2017.LM386 Low Voltage Audio Power Amplifier. Texas Instruments Incorporated. https://www.ti.com/lit/ds/symlink/lm386.pdf. Accessed 25 July 2020.

[34] Christopher, B., SheenaMary, Y., Khandaker, M.U., and Jojo, P. 2021. Empirical study on specific absorption rate of head tissues due to induced heating of 4G cell phone radiation. Radiation Physics and Chemistry, 178, 108910.

[35] Hoque,F., Hossain,S., Mollah,S.2013. A study on specific absorption rate (SAR) due to non-ionizing radiation from wireless/telecommunication in Bangladesh American Journal of Physics and Applications. **1**(3): 104-110

[36] Wessapan,T., Srisawatdhisukul, S. and Rattanadecho,P.2012. Specific absorption rate and temperature distributions in human head subjected to mobile phone radiation at different frequencies, International Journal of Heat and Mass Transfer **55**: 347–359.

[37] Hoque,F., Hossain,S., Mollah,S.2013. A study on specific absorption rate (SAR) due to non-ionizing radiation from wireless/telecommunication in Bangladesh American Journal of Physics and Applications. **1**(3): 104-110

[38] Bhargava, D., Leeprechanon, N., Rattanadecho, P., Wessapan, T. 2019. Specific absorption rate and temperature elevation in the human head due to overexposure to mobile phone radiation with different usage patterns, International Journal of Heat and Mass Transfer. 130: 1178–1188.

[39] Levis, A.G., Minicuci, N., Ricci, P., Gennaro, V. and Garbisa, S. 2011. Mobile phones and head tumors. The discrepancies in cause-effect relationships in the epidemiological studies - how do they arise? Environmental Health.**10**(59):1-15

[40] Cardis, E.,Deltour, I. and Vrijheid, M. 2010.Brain tumour risk in relation to mobile telephone use: results of the INTERPHONE international case-control study. International Journal of Epidemiology.**39**(3):675-694.

[41] Ahmed, M. 2009. Investigating Radiation Hazard and Safety Aspects of Handheld Mobile," 2009 Third International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies, 33: 1-9.

[42] Khurana, V. G., Teo, C., Kundi, M ., Hard ell, L., and Carlberg, M.2009. Cell phones and brain tumors: a review including the long-term epidemiologic data. Surgical Neurology. 72:205 –2 15.

[43] Hardell, L., Carlberg, M., and Mild, K. H.2011. Pooled analysis of case-control studies on malignant brain tumours and the use of mobile and cordless phones including living and deceased subjects. International Journal of Oncology, **38**(5), 1465 –14 74.

[44] Blackman C. 2009.Cell phone radiation: Evidence from ELF and RF studies supporting more inclusive risk identification and assessment. Pathophysiology. 2009 .**16**(2-3):205-16.

[45] Kaburcuk, F.2019. Effects of a brain tumor in a dispersive human head on SAR and temperature rise distributions due to RF sources at 4G and 5G frequencies. Electromagnetic Biology and Medicine.**38**(2):168-176.

[46] Chavdoula, E.D., Panagopoulos, D.J., Margaritis, L.H. 2010.Comparison of biological effects between continuous and intermittent exposure to GSM-900-MHz mobile phone radiation: Detection of apoptotic cell-death features. Mutation Research/Genetic Toxicology and Environmental Mutagenesis.700:51-61

[47] Odemer, R. Odemer, F.2019. Effects of radiofrequency electromagnetic radiation (RF-EMF) on honey bee queen development and mating success. Science of the Total Environment. 661:553-562.

[48] Ahamed, V.I., Karthick, N.G., Joseph, P.K. 2008.Effect of mobile phone radiation on heart rate variability. Computers in Biology and Medicine.**38**(6):709-712.

[49] Phillips, J.L., Singh, N.P., Lai, H.2009. Electromagnetic fields and DNA damage. Pathophysiology. **16**(2):79-88.

[50] Shahin S, Singh SP, Chaturvedi CM. Mobile phone (1800MHz) radiation impairs female reproduction in mice, Mus musculus, through stress induced inhibition of ovarian and uterine activity. Reprod Toxicol.73:41-60.

[51] Rongen,E.V.,Croft, R.,Juutilainen, J., Lagroye, I., Miyakoshi,J. and Saunders, R.2009. Effects of Radiofrequency Electromagnetic Fields on the Human Nervous System. Journal of Toxicology and Environmental Health. **12**(8): 572-597.

[52] Wallace, J., Selmaoui, B.2019. Effect of mobile phone radiofrequency signal on the alpha rhythm of human waking EEG: A review. Environmental Research.175:274-286.

[53] Sallomi, A.H.2012. A Theoretical Approach for SAR Calculation in Human Head Exposed to RF. Journal of Engineering and Development. **16**(4):304-313.

[54] Jeladze, V., Nozadze, T. , Petoev,D. and Partsvania, B. 2019. Mobile phone antenna-matching study with different finger positions on an inhomogeneous human model. Electromagnetic Biology and Medicine. **38**(3): 297-306.

APPENDIX

A-1: MATLAB program for represent the effect of frequency and distance on SAR

```
clc
clear all
close all
load('D_S.mat')
load('F_S.mat')
load('SAR_S.mat')
load('SAR_F.mat')
load('SAR_B.mat')
load('SAR_Br.mat')
load('SAR_M.mat')
load('SAR_E.mat')
figure
surf(D_S,F_S,SAR_S)
xlabel({'Distance (mm)'},'FontSize',14,'FontName','Times New Roman');
ylabel({'Frequency (MHz)'},'FontSize',14,'FontName','Times New Roman');
zlabel({'SAR (W/Kg)'},'FontSize',14,'FontName','Times New Roman');
colorbar([0.945810247244562 0.099490560383578 0.0238308013106941
0.802068557919622]);
%colorbar('location','north')
annotation('textbox', [0.914582723279648 0.88999230363418 0.0524743777452418
0.0629213483146067],...
'String','Max:1.37','FontSize',14,'FontName','Times New Roman','LineStyle','none',
'EdgeColor',[0.831372549019608 0.815686274509804 0.784313725490196]);
annotation('textbox', [0.917276720351392 0.0385728486826916 0.0907759882869693
0.0629213483146067],...
'String','Min:0.01','FontSize',14,'FontName','Times New Roman','LineStyle','none',
'EdgeColor',[0.831372549019608 0.815686274509804 0.784313725490196]);
figure
surf(D_S,F_S,SAR_F)
```

```
xlabel({'Distance (mm)'},'FontSize',14,'FontName','Times New Roman');
ylabel({'Frequency (MHz)'},'FontSize',14,'FontName','Times New Roman');
zlabel({'SAR (W/Kg)'},'FontSize',14,'FontName','Times New Roman');
colorbar([0.945810247244562 0.099490560383578 0.0238308013106941
0.802068557919622]);
%colorbar('location','north')
annotation('textbox', [0.914582723279648 0.88999230363418 0.0524743777452418
0.0629213483146067],...
'String','Max:0.139','FontSize',14,'FontName','Times New Roman','LineStyle','none',
'EdgeColor',[0.831372549019608 0.815686274509804 0.784313725490196]);
annotation('textbox', [0.917276720351392 0.0385728486826916 0.0907759882869693
0.0629213483146067],...
'String','Min:0.0008','FontSize',14,'FontName','Times New Roman','LineStyle','none',
'EdgeColor',[0.831372549019608 0.815686274509804 0.784313725490196]);
figure
surf(D_S,F_S,SAR_B)
xlabel({'Distance (mm)'},'FontSize',14,'FontName','Times New Roman');
ylabel({'Frequency (MHz)'},'FontSize',14,'FontName','Times New Roman');
zlabel({'SAR (W/Kg)'},'FontSize',14,'FontName','Times New Roman');
colorbar([0.945810247244562 0.099490560383578 0.0238308013106941
0.802068557919622]);
%colorbar('location','north')
annotation('textbox', [0.914582723279648 0.88999230363418 0.0524743777452418
0.0629213483146067],...
'String','Max:0.18','FontSize',14,'FontName','Times New Roman','LineStyle','none',
'EdgeColor',[0.831372549019608 0.815686274509804 0.784313725490196]);
annotation('textbox', [0.917276720351392 0.0385728486826916 0.0907759882869693
0.0629213483146067],...
'String','Min:0.0006','FontSize',14,'FontName','Times New Roman','LineStyle','none',
'EdgeColor',[0.831372549019608 0.815686274509804 0.784313725490196]);
figure
surf(D_S,F_S,SAR_Br)
xlabel({'Distance (mm)'},'FontSize',14,'FontName','Times New Roman');
```

```
ylabel({'Frequency (MHz)'},'FontSize',14,'FontName','Times New Roman');
zlabel({'SAR (W/Kg)'},'FontSize',14,'FontName','Times New Roman');
colorbar([0.945810247244562 0.099490560383578 0.0238308013106941
0.802068557919622]);
%colorbar('location','north')
annotation('textbox', [0.914582723279648 0.88999230363418 0.0524743777452418
0.0629213483146067],...
'String','Max:2.8','FontSize',14,'FontName','Times New Roman','LineStyle','none',
'EdgeColor',[0.831372549019608 0.815686274509804 0.784313725490196]);
annotation('textbox', [0.917276720351392 0.0385728486826916 0.0907759882869693
0.0629213483146067],...
'String','Min:0.0177','FontSize',14,'FontName','Times New Roman','LineStyle','none',
'EdgeColor',[0.831372549019608 0.815686274509804 0.784313725490196]);
figure
surf(D_S,F_S,SAR_M)
xlabel({'Distance (mm)'},'FontSize',14,'FontName','Times New Roman');
ylabel({'Frequency (MHz)'},'FontSize',14,'FontName','Times New Roman');
zlabel({'SAR (W/Kg)'},'FontSize',14,'FontName','Times New Roman');
colorbar([0.945810247244562 0.099490560383578 0.0238308013106941
0.802068557919622]);
%colorbar('location','north')
annotation('textbox', [0.914582723279648 0.88999230363418 0.0524743777452418
0.0629213483146067],...
'String','Max:1.68','FontSize',14,'FontName','Times New Roman','LineStyle','none',
'EdgeColor',[0.831372549019608 0.815686274509804 0.784313725490196]);
annotation('textbox', [0.917276720351392 0.0385728486826916 0.0907759882869693
0.0629213483146067],...
'String','Min:0.01','FontSize',14,'FontName','Times New Roman','LineStyle','none',
'EdgeColor',[0.831372549019608 0.815686274509804 0.784313725490196]);
figure
surf(D_S,F_S,SAR_E)
xlabel({'Distance (mm)'},'FontSize',14,'FontName','Times New Roman');
ylabel({'Frequency (MHz)'},'FontSize',14,'FontName','Times New Roman');
```

```
zlabel({'SAR (W/Kg)'},'FontSize',14,'FontName','Times New Roman');
colorbar([0.945810247244562 0.099490560383578 0.0238308013106941
0.802068557919622]);
%colorbar('location','north')
annotation('textbox', [0.914582723279648 0.88999230363418 0.0524743777452418
0.0629213483146067],...
'String','Max:2.946','FontSize',14,'FontName','Times New Roman','LineStyle','none',
'EdgeColor',[0.831372549019608 0.815686274509804 0.784313725490196]);
annotation('textbox', [0.917276720351392 0.0385728486826916 0.0907759882869693
0.0629213483146067],...
'String','Min:0.0188','FontSize',14,'FontName','Times New Roman','LineStyle','none',
'EdgeColor',[0.831372549019608 0.815686274509804 0.784313725490196]);
```

A-2 MATLAB program for represent the comparison of SAR between adult and child

```
clc
clear all
close all
load('SAR_125.mat')
b=SAR_125;
figure
bar(b);
xlabel('Tissue Name');
ylabel('SAR (W/Kg)');
set(gca,'XTickLabel',{'Skin','Fat','Bone','Brain','Eye'})
legend({'Adult','Child'})
annotation('line',[0.130678728299519 0.905678728299519],...
[0.760904761904762 0.75952380952381],'LineWidth',2,'Color',[1 0 0]);
annotation('textbox',...
[0.415812591508053 0.827092243186583 0.118594436310395
0.0587002096436059],...
'String',{'ICNIRP Limit of 2 W/Kg'},...
```

```
'LineStyle','none');
% Create arrow
annotation('arrow',[0.523426061493411 0.551244509516837],...
[0.835477987421384 0.771488469601677],'LineWidth',1);
load('SAR_250.mat')
b=SAR_250;
figure
bar(b);
xlabel('Tissue Name');
ylabel('SAR (W/Kg)');
set(gca,'XTickLabel',{'Skin','Fat','Bone','Brain','Eye'})
legend({'Adult','Child'})
annotation('line',[0.131410792721188 0.906410792721188],...
[0.471648563557655 0.470267611176703],'LineWidth',2,'Color',[1 0 0]);
annotation('textbox',...
[0.38579795021962 0.577092243186585 0.118594436310395 0.0587002096436059],...
'String',{'ICNIRP Limit of 2 W/Kg'},...
'LineStyle','none');
% Create arrow
annotation('arrow',[0.495607613469986 0.523426061493412],...
[0.558618483289154 0.494628965469447],'LineWidth',1);
load('SAR_1.mat')
b=SAR_1;
figure
bar(b);
xlabel('Tissue Name');
ylabel('SAR (W/Kg)');
set(gca,'XTickLabel',{'Skin','Fat','Bone','Brain','Eye'})
legend({'Adult','Child'})
annotation('line',[0.13087774461535 0.90587774461535],...
[0.381873704270602 0.38049275188965],'LineWidth',2,'Color',[1 0 0]);
annotation('textbox',...
[0.38579795021962 0.477498747251629 0.118594436310395 0.058700209643606],...
```

```
'String',{'ICNIRP Limit of 2 W/Kg'},...
'FitBoxToText','off',...
'LineStyle','none');
% Create arrow
annotation('arrow',[0.495607613469986 0.523426061493412],...
[0.467155068655011 0.403165550835304],'LineWidth',1);
load('SAR_2.mat')
b=SAR_2;
figure
bar(b);
xlabel('Tissue Name');
ylabel('SAR (W/Kg)');
set(gca,'XTickLabel',{'Skin','Fat','Bone','Brain','Eye'})
legend({'Adult','Child'})
annotation('line',[0.13087774461535 0.90587774461535],...
[0.245694842481986 0.244313890101034],'LineWidth',2,'Color',[1 0 0]);
annotation('textbox',...
[0.360175695461202 0.320994682210982 0.118594436310395 0.058700209643606],...
'String',{'ICNIRP Limit of 2 W/Kg'},...
'FitBoxToText','off',...
'LineStyle','none');
% Create arrow
annotation('arrow',[0.473645680819913 0.501464128843339],...
[0.330976206866394 0.266986689046687],'LineWidth',1);
```

A-3: MATLAB program for represent the temperature change

```
clc
clear all
close all
load('F_800.mat')
load('T.mat')
figure
```

```
plot(T,F_800);
xlabel('Exposure Time (s)');
ylabel('Temperature Increase (  ^oC  )');
%set(gca,'XTickLabel',{'Skin','Fat','Bone','Brain','Muscle','Eye'})
legend({'Skin','Fat','Bone','Brain','Muscle','Eye'})
load('F_900.mat')
figure
plot(T,F_900)
xlabel('Exposure Time (s)');
ylabel('Temperature Increase (  ^oC  )');
%set(gca,'XTickLabel',{'Skin','Fat','Bone','Brain','Eye','Muscle'})
legend({'Skin','Fat','Bone','Brain','Muscle','Eye'})
load('F_1600.mat')
figure
plot(T,F_1600)
xlabel('Exposure Time (s)');
ylabel('Temperature Increase (  ^oC  )');
%set(gca,'XTickLabel',{'Skin','Fat','Bone','Brain','Eye','Muscle'})
legend({'Skin','Fat','Bone','Brain','Muscle','Eye'})
load('F_1800.mat')
figure
plot(T,F_1800)
xlabel('Exposure Time (s)');
ylabel('Temperature Increase (  ^oC  )');
%set(gca,'XTickLabel',{'Skin','Fat','Bone','Brain','Eye','Muscle'})
legend({'Skin','Fat','Bone','Brain','Muscle','Eye'})
load('F_2000.mat')
figure
plot(T,F_2000)
xlabel('Exposure Time (s)');
ylabel('Temperature Increase (  ^oC  )');
%set(gca,'XTickLabel',{'Skin','Fat','Bone','Brain','Eye','Muscle'})
legend({'Skin','Fat','Bone','Brain','Muscle','Eye'})
```

```
load('F_2100.mat')
figure
plot(T,F_2100)
xlabel('Exposure Time (s)');
ylabel('Temperature Increase (  ^oC  )');
%set(gca,'XTickLabel',{'Skin','Fat','Bone','Brain','Eye','Muscle'})
legend({'Skin','Fat','Bone','Brain','Muscle','Eye'})
load('F_2500.mat')
figure
plot(T,F_2500)
xlabel('Exposure Time (s)');
ylabel('Temperature Increase (  ^oC  )');
%set(gca,'XTickLabel',{'Skin','Fat','Bone','Brain','Eye','Muscle'})
legend({'Skin','Fat','Bone','Brain','Muscle','Eye'})
load('F_2600.mat')
figure
plot(T,F_2600)
xlabel('Exposure Time (s)');
ylabel('Temperature Increase (  ^oC  )');
legend({'Skin','Fat','Bone','Brain','Muscle','Eye'})
load('F_3000.mat')
figure
plot(T,F_3000)
xlabel('Exposure Time (s)');
ylabel('Temperature Increase (  ^oC  )');
legend({'Skin','Fat','Bone','Brain','Muscle','Eye'})
load('F_3400.mat')
figure
plot(T,F_3400)
xlabel('Exposure Time (s)');
ylabel('Temperature Increase (  ^oC  )');
legend({'Skin','Fat','Bone','Brain','Muscle','Eye'})
load('F_3500.mat')
```

```
figure
plot(T,F_3500)
xlabel('Exposure Time (s)');
ylabel('Temperature Increase (  ^oC  )');
legend({'Skin','Fat','Bone','Brain','Muscle','Eye'})
load('F_3600.mat')
figure
plot(T,F_3600)
xlabel('Exposure Time (s)');
ylabel('Temperature Increase (  ^oC  )');
legend({'Skin','Fat','Bone','Brain','Muscle','Eye'})
```