SPECIFIC ABSORPTION RATE IN THE HUMAN HEAD DUE TO METAL-FRAME GLASSES AND EAR PROSTHESIS

by

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A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy (Communication Engineering)

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2015

ACKNOWLEDGEMENT

Alhamdulillah, foremost, I would like to express my gratitude to my supervisor, Assoc. Prof. Dr. Mohd Fareq Abd Malek for the useful comments, remarks and engagement through the learning process of this thesis. I could not have imagined having a better supervisor.

Apart from the efforts of me, the success of this research depends largely on the encouragement and guidelines of many others. I take this opportunity to express my gratitude to the people who have been instrumental in the successful completion of this research. I would like to show my greatest appreciation to my co-supervisor, Prof. Dr. Syed Idris Syed Hassan, for enlightening me the first glance of research besides their encouragement, insightful comment.

Most importantly, none of this would have been possible without the love and patience of my family. My words will fail to express my heartfelt thanks especially to my beloved wife, Nurul Husna Abd Wahab, who has supported me throughout entire process, both by keeping me harmonious and helping me putting pieces together. And also my little, brilliant son, Muhammad Ayyash Muinuddin for inspiring me to work harder. I will be grateful forever for your love. As for my parent, receive my deepest gratitude and love for their endless love and support through these years.

Last but not least, I would like to thank the Advanced Communication Engineering (ACE), especially Assoc. Prof. Ir. Dr. Mohd Faizal bin Jamlos for aiding measurement tools. I am grateful for their constant support and help.

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LIST OF ABBREVIATIONS

CAD	Computer aided design
CT	Computerized x-ray tomography
dB	Decibels
EM	Electromagnetic
EMF	Electromagnetic fields
FCC	Federal Communications Commission
FDTD	Finite-difference time-domain
ICNIRP	International Commission Non-Ionizing Radiation Protection
MRI	Magnetic resonance imaging
PEC	Perfect electrical conductor
RF	Radio frequency
SAM	Standard anthropomorphic model
SAR	Specific absorption rate
TSL	Tissue Simulating Liquid

LIST OF SYMBOLS

B	Magnetic flux density (W/m²)
c	Speed of light (m/s)
C	Specific heat capacity (J/Kg·K)
D	Electric flux density (D/m²)
E	Electric field
Je	Electric current (A/m²)
Jm	Magnetic current (V/m²)
SAR	Specific absorption rate (W/Kg)
λ	Wavelength (m)
σ	Conductivity (S/m)
ε	Electric permittivity (F/m)
μ	Magnetic permeability (H/m)
ρ	Density (Kg/m³)

Kadar Penyerapan Khusus di Kepala Manusia Disebabkan Oleh Cermin Mata Bingkai-besi dan Prostesis Telinga

ABSTRAK

Kajian di dalam tesis ini melibatkan penyiasatan kadar penyerapan tertentu (SAR) dalam model kepala manusia didedahkan kepada medan elektromagnet. SARs (1-g dan 10-g) telah dibandingkan dalam beberapa model kepala manusia. Siasatan ini bertujuan mengkaji kesan penggunaan cermin mata bingkai logam dan implan telinga prostetik yang realistik dikekalkan disambung pada sisi kepala. Satu set antena dwi-kutub yang beroperasi pada frekuensi umum 900, 1800 dan 2100 MHz telah dipusingkan untuk mengkaji kesan frekuensi dan polarisasi. Dua situasi dipertimbangkan dalam tesis; radiasi di bahagian hadapan muka, dan bahagian sisi kepala. Kajian awal telah dijalankan dengan menggunakan model kepala yang ringkas dan objek logam untuk meminimakan tempoh simulasi. Empat jenis kepala bergeometri ringkas digunakan; bata, silinder, sfera dan silinder yang berbentuk elip disimulasikan dengan hidung dan tanpa hidung yang berbentuk ringkas untuk menyiasat sebarang kesan. Pada masa yang sama, rod logam lurus pada awalnya digunakan untuk mewakili cermin mata bingkai logam. Parameter telah diperluaskan lagi terhadap keberaliran rod logam yang berbeza, dimensi sebuah model kepala, kelengkungan rod dan jejari rod. Dalam kes radiasi sebelah sisi, penyiasatan telinga prostesis telah dimulakan dengan melihat kesan sifat dielektrik telinga tiruan yang berbeza. Selain itu, penggunaan gabungan objek logam ini yang mempunyai bentuk realistik bagi kedua-dua cermin mata dan implan (telinga) telah dikaji lebih terperinci dengan menggunakan model kepala manusia homogen dan heterogen. Keputusan ujikaji ini mencadangkan bahagian lain implan tersebut beresonansi bergantung pada frekuensi dan polarisasi, dan selanjutnya, menunjukkan bahawa implan ini nyata adalah elemen penyerakan. Implan menumpukan, fokus dan memantulkan tenaga frekuensi radio. Tisu yang berhampiran kepala juga akan mempunyai kesan muatan dielektrik sekunder. Peningkatan relatif kepada SAR_{10g} kerana implan yang jauh lebih kecil. Taburan SAR menunjukkan bahawa peningkatan pada SAR kerana implan logam tersebut amat setempat. Ini menerangkan perubahan dalam SAR_{1g}dan perubahan yang jauh lebih kecil untuk 10g SAR. Walau bagaimanapun, cermin mata bingkai logam yang dipilih dalam penyiasatan ini telah menunjukkan kenaikan SARs tidak ketara pada semua orientasi dwi-kutub dan frekuensi yang dipilih. Secara keseluruhannya, dengan mengambil kira telinga prostesis, pendedahan kepada 900 MHz daripada sebarang peranti berdekatan dengan implan tersebut mungkin boleh mengakibatkan kemudaratan. Ia juga dicadangkan supaya pesakit yang mempunyai telinga prostetik ini tidak boleh didedahkan kepada sebarang bentuk alat perhubungan berhampiran-badan pada sebarang julat frekuensi, kerana terdapat bukti bahawa logam diimplan di dalam bahan-bahan tertentu mempunyai perilaku berlainan untuk logam yang sama yang belum ditanam dalam sebarang bahan.

Specific Absorption Rate in the Human Head due to Metal-frame Glasses and Ear Prosthesis

ABSTRACT

The research in this thesis involves the investigation of the specific absorption rate (SAR) in a human head model exposed to electromagnetic fields. The SARs (1-g and 10-g) were compared inside various models of the human head. Investigation is aimed at the study of the effect of the use of a realistic implant retained prosthetic ear attached to the side of the head and metal-frame glasses. A set of dipole antennas operating at a common frequency of 900, 1800 and 2100 MHz were rotated to investigate the effect of frequency and polarization. Two situations were considered in the thesis; radiation at the front of the face, and at the side of the head. Initial studies were conducted using a simplified model of the head and metal object to minimize the duration of the simulation. Four types of simple geometrical head were used; brick, cylindrical, spherical and elliptical cylinders were simulated with and without the simple shape of the nose to investigate its possible effects. At the same time, a straight metal rod was initially employed to represent the metal-frame glasses. The parameters were further expanded to the different conductivities of the metal rod, the dimensions of a model of the head, the curvature of the rod and the radii of the rod. In the side radiation case, the investigation of the ear prosthesis was initiated by looking at the effect of different dielectric properties of the artificial ear. Moreover, the combined use of these metal objects with realistic shapes of both glasses and implant (ear) were investigated in detail using homogeneous and heterogeneous models of a human head. The results suggest that different sections of the implant resonate depending on the frequency and polarization, and furthermore, demonstrate that this real implant is a complex scattering element. The implant focuses and reflects the incident radio frequency (RF) energy. The nearby tissue of the head will also have a secondary dielectric loading effect. The relative enhancement on the SAR_{10g} due to the implant was much smaller. The SAR distribution shows that the increase in the SAR due to the metallic implant is extremely local with regards to the implant. This explains the change in the SAR_{1g} and the much smaller changes to the 10g SAR. However, the metal-frame glasses selected in this investigation had given a negative significant increment of SARs at any orientation of the dipole and frequency chosen. Overall, with regard to the ear prosthesis, exposure to 900 MHz from any device adjacent to the implant may cause harm. It also is suggested that patients with ear prostheses should not be exposed to any near-body communication at any frequency range, because there is evidence that metal implanted inside certain materials has different behavior from the same metal that has not been implanted in any material.

CHAPTER 1

INTRODUCTION

1.1 Background

In 1865, Maxwell formulated a set of equations as a first introduction to electromagnetic (EM) theory. The possibility of transmitting EM signals through the air was discovered in the late 19th century, but only in the past two decades the wireless communications become available to the general public, most notably through mobile phones. Over that period of time, the mobile communications industry has become economically important, especially in Finland, and a significant amount of research has managed to enhance the quality of wireless systems.

Radio frequency (RF) engineering and modern microwave engineering are exciting and vigorous topics, due in large part to the interaction between the advances in modern electronic technology and the increasing in demand for voice, data, and video communication capacity. Due to this major improvement in communications, mobile communication devices operating in the RF range have flourished rapidly in the market. Most notably, the smartphone almost has become a basic need for everyone. However, over the past few years, the possible consequences of the use of mobile phones on human health has been investigated by several researchers, (e.g., McIntosh, Anderson, & McKenzie, 2005; Siriwitpreecha, Rattanadecho, & Wessapan, 2013; Virtanen, Huttunen, Toropainen, & Lappalainen, 2005; Virtanen, Keshvari, & Lappalainen, 2007).

Mobile phones are placed in close proximity to the user's head, hence, a certain amount of EM energy is absorbed by the head rather than being directly radiated. In addition, as the technology continues to improve, mobile phones will be used for various purposes and, therefore, the users will be exposed to EM energy for longer periods every day (Rahmat-Samii & Stutzman, 1998; W. G. Whittow, Edwards, Panagamuwa, & Vardaxoglou, 2008), and this may compound any possible health effects.

1.2 Problem Statement

The health effects of using mobile phones have been studied extensively in the past. Consequently, mandatory safety limits for RF energy absorption by human tissue have been established throughout the world. In order to minimize the heating effect on tissue caused by the absorption of RF energy by the human body, all mobile communications equipment (MCE) must comply with the regulations that establish the maximum power output of mobile phones.

The specific absorption rate (SAR) is used to evaluate the rate of absorption of energy by human tissue, and spatially-averaged SAR limits have been promulgated worldwide. For example, in the U.S. and Europe, the limits are 1.6 W/kg over 1 g of tissue and 2 W/kg over 10 g of tissue, respectively (ICNIRP, 1998; IEEE, 2005). Although RF emissions from mobile MCE are carefully regulated, the possibility exists that the RF characteristics are altered somewhat when tissue is irradiated by RF energy, thereby increasing the SAR.

Concern about the possible health effects due to exposure to electromagnetic fields (EMF) has increased among health professionals and the general public since these communication devices were developed (Bernardi, Cavagnaro, Pisa, & Piuzzi, 2000; Cooper, & Hombach, 1996). This concern has caused an increase in the research conducted on the rate at which electromagnetic radiation is absorbed by the human body (Bernardi et al., 2000; Cooper & Hombach, 1998; Dimbylow, 2011). The issue is complicated further by the presence of any metal objects that may affect the characteristics of the EM radiation.

Furthermore, with recent advances in technology, mobile phones have been incorporated in a number of applications that require the device to be held in front of the face while transmitting. This introduces a new scenario in which both the side of the user's head and the user's face are exposed to the radiation source, which may be coupled with metal objects. In the past, several objects have been shown to alter the level of RF energy absorbed, including medical implants (Virtanen et al., 2007), metal-frame glasses (Troulis, Evans, Scanlon, & Trombino, 2003; W.G. Whittow & Edwards, 2004), and metal jewelry (W. G. Whittow et al., 2008).

More than a decade ago, rapid prototyping (RP) techniques began to be used extensively in maxillofacial surgery. This technique concentrates on producing exact physical replicas of patients' skeletal anatomy, and surgeons and prosthetists use the replicas to help plan reconstructive surgery and prosthetic rehabilitation. Developments in this area are moving rapidly towards the use of complex technologies to design and produce implants that make custom-fitted prostheses a reality. The definitive treatment for traumatic loss of an ear and poor surgical reconstruction often are followed by an implant-retained auricular prosthesis. As a result, there is increasing concern on the part of such patients about the health and safety aspects of such prostheses given the increasing use of RF devices, such as mobile phones, in close proximity to metal implants. In their initial study, Cooper & Hombach, (1996) concluded that the amount of RF absorption within a homogeneous head model was enhanced substantially in the presence of metal implants. For example, the method used to retain an auricular prosthesis requires the use of a metal bar and a metal clip.

Thus, given the widespread application of bar and clip mechanisms in the production of prostheses for ears, it was deemed imperative to evaluate the compatibility between metal implants and EMF from RF devices, but, to date, this has not been done.

Furthermore, the combination of metal-frame glasses and an ear prosthesis could possibly result in a significant increase in the SAR. Again, no research addressing this issue can be found in the literature. It is hypothesized that SARs might increase at certain angles of incidence and frequency when the resonant frequency matches the length of the metal objects and is parallel to the excitation sources. It is predicted that an embedded metal implant inside different ear's tissues permittivity will produce different effects.

1.3 Objectives of the Research Work

The main objectives are to analyze the worst-case effects of metal-frame glasses and prosthetic ear implants on the SAR of energy by a human head when a subject is using common RF sources. The sources considered were mobile phones operating at 900, 1800, and 2100 MHz. The specific objectives are as follows:

- To determine the parameters that influence the RF energy coupling effect of a conductive metal rod in the human head.
- To model a 3D, realistic, metal-frame pair of glasses and an ear prosthesis for simulation in order to investigate the effect on human tissue.
- To evaluate the effect of an RF energy source on the SAR of a human head in the presence of both an ear prosthesis and metal-frame glasses.

1.4 Contribution of the Thesis

Changes in the SAR caused by metal objects in the presence of an RF energy source have received limited attention in the literature. In this thesis, the SAR in a model of a head exposed to EMF was analyzed while there was a 3D, implant-retained prosthetic ear attached to the side of the head. In addition, 3D, metal-frame glasses were added to evaluate the worst case scenario, i.e., when the person using the mobile phone has both of these metal objects on her or his head.

Different models of the human head were considered in the study. A simple homogeneous, spherical model of the head was used to validate the simulation with published results. Secondly, the head of a homogeneous specific anthropomorphic mannequin (SAM) used to observe the amount of RF energy the head absorbed. Then, the results were compared with the more realistic voxel model of the human head. Also, a cubical model of the head was used to compare the measurement and simulation results.

This thesis includes the effect of a real ear prosthesis and metal-frame glasses. To date, there have been very few research publications concerning the effect of an ear implant, i.e., cochlear implant, on the SAR in the head. However, it has been proven that the presence of metal objects enhances the SAR. Thus, this thesis makes a new, important contribution to the knowledge in the field of bio-electromagnetics.

1.5 Thesis Outline

The thesis consists of six chapters, and the following five chapters are organized as follows; Chapter 2 provides a critical review of the effect of a metal object on the SAR, basic SARs for simulation and measurement, and the factors that affect the SAR. In this chapter, the interactions between the antenna, the human head, and metal objects also are discussed.

Chapter 3 deals with the methods and tools that were used in this research to investigate RF interactions with biological bodies. Chapter 3 also provides the validation procedure used to ensure that the simulation setup was designed appropriately before the simulation was conducted.

In Chapter 4, the results of the simulations are analyzed using tissue simulating liquid (TSL). In this chapter, four simple geometrical model of heads phantom are discussed with emphasis on the effect of the simple head with and without a simple geometrical human nose. The other parameters are varied in this chapter to determine the parameters that have the greatest effect on the SAR. The effects of orienting the dipole antenna in different directions were evaluated.

Chapter 5 investigated in detailed base on the results obtained from TSL and further studied with the voxel model of the human head for using the same source from an earlier chapter. The maximum SAR was studied in this chapter using the basis of the maximum SAR obtained from Chapter 4. This chapter also shows the measurement results that indicate the effects of the metal objects on the SAR inside the cube head phantom model that filled with tissue-equivalent liquid.

Chapter 6 provides the conclusions based on the results of the simulations and experimental tests. Also, some recommendations for future work are presented.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In RF communication, there are two types of EMF situation; one is near field and the other is far field. In free space, the far field is straight forward because the electric field and the magnetic field are perpendicular to each other. In the context of analyzing the far field effect, exposure from a regular base station and simulation using a plane wave are used. Unlike the near field, the far field is much complex. In analyzing the near field for a device, such as a mobile phone used in close proximity to tissues, it is difficult to predict the EM field and other characteristics, since certain parts of the mobile phone scatter and reflect the EMF. The rationale for the studies of the effect of far field exposure is the work-related, high-level exposure of personnel while conducting their assigned tasks. Conversely, studies of the effect of near field exposure have resulted from public concern about the health risk associated with the use of RF devices in close proximity to the body. At the same time, carrying a metal object theoretically may enhance the possibility of RF absorption in certain cases. This is due to the complex reaction that occurs when EMF comes in contact with the surface of the human body. The transmitted RF energy may be absorbed by the human tissue (body), and or it may be reflected. The amounts of energy that are absorbed and reflected vary with the dielectric properties, the frequency of exposure, the shape of the exposed tissue, the angle of incidence, and the electrical conductivity of the tissues (Johnson &

Guy, 1972; Rani & Raju, 2013). Moreover, this absorption in the lossy tissues attenuates as the RF energy is absorbed by the tissue. In this chapter, reviews from the most-cited prior publications related to this research are discussed to determine their relevance and significance.

2.2 Radiation from Mobile Phones

Mobile phones broadcast in the microwave region, which is non-ionizing radiation. RF waves belong to the category of non-ionizing radiation because they cannot break chemical bonds or extract electrons from atoms, causing mater ionizing. Ionizing radiation causes biological effects because it breaks chemical bonds and creates ions. Thus, ionizing radiation is far more dangerous than non-ionizing radiation because it can cause distortions of the genetic and cause cancer (Holton, 2009). Figure 2.1 shows the microwave region of the electromagnetic spectrum.

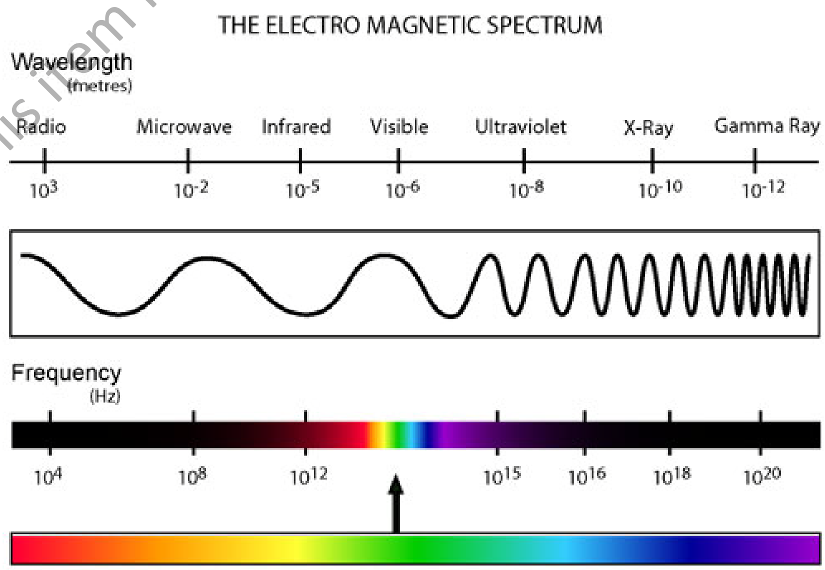

Figure 2.1: Electromagnetic spectrum ("electromagnetic spectrum," n.d.).