PLANAR INVERTED-F ANTENNA (PIFA):
A STUDY OF SPECIFIC ABSORPTION RATE (SAR) BY USING DUAL FREQUENCIES IN MOBILE COMMUNICATIONS

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ABSTRACT

Planar inverted-F antenna formerly known as PIFA is a very low profile antenna, promising to be a very good candidate, less easily broken off, reduced power absorption by the head and less sensitive to the geometry of the structure. This type of antenna is mostly used in mobile phone today. By using CST Microwave Studio, PIFA is designed to analyse its performance and Specific Absorption Rate (SAR) with the COST244 spherical head model at different distances. The PIFA is operating at the frequency of 900 MHz and 1800 MHz which fulfilled the recent applications of Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS). The SAR simulation is specified at 1 g and 10 g.

ABSTRAK

Planar inverted-F antenna dikenali sebagai PIFA adalah antenna yang berprofil sangat rendah, berpotensi untuk menjadi pilihan yang sangat baik, tidak mudah pecah, mengurangkan penyerapan kuasa di kepala dan tidak sensitif terhadap struktur geometri. Jenis antenna ini kebanyakannya digunakan di dalam telefon bimbit hari ni. Dengan menggunakan CST Microwave Studio, PIFA direkabentuk untuk dianalisis kemampuannya dan *Specific Absorption Rate (SAR)* dengan model kepala sfera COST244 pada jarak yang berbeza. PIFA beroperasi pada frekuensi 900 MHz dan 1800 MHz yang menepati aplikasi terkini *Global System for Mobile Communications (GSM)* dan *Universal Mobile Telecommunications System (UMTS)*. Simulasi *SAR* dinyatakan pada 1 g dan 10 g.

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LIST OF ABBREVIATION

EM	-	electromagnetic
SAR	-	specific absorption rate
ICNIRP	-	International Commission of Non-Ionizing Radiation Protection
IEEE	-	Institute of Electrical and Electronics Engineers
FCC	-	Federal Communication Commissions
SAM	-	specific anthropomorphic mannequin
PIFA	-	planar inverted-F antenna
COST422	-	Cooperation in the Field Scientific and Technical Research
CST	-	Computer Simulation Technology
GSM	-	Global System for Mobile Communications
UMTS	-	Universal Mobile Telecommunications System
WHO	-	World Health Organization
C	-	Celcius
RF	-	radio frequency
ELF	-	Extremely Low Frequency
MRI	-	Magnetic Resonance Imaging
IF	-	Intermediate Frequency
DNA	-	deoxyribonucleic acid
SCC	-	Standards Coordinating Committee
SC	-	Sub Committee
WG	-	Working Group
CENELEC	-	European Committee for Electrical Standardization

VSWR	-	voltage standing wave ratio
FDTD	-	finite difference time domain
MHz	-	Mega Hertz
PCB	-	printed circuit board
L	-	Length
W	-	width
d	-	distance
FR-4	-	Flame Retardant-4
HSL	-	head tissue simulating liquid
3-D	-	three dimension

CHAPTER 1

INTRODUCTION

1.1 Project background

In the recent of last few years, the demands on mobile phone performance have increased rapidly [1, 2]. Hence, the evaluation based on the interaction between human body and the electromagnetic (EM) field [3] is increasing. This measurement process known as peak spatial-average specific absorption rate (SAR) which need to be followed by engineers and other specialists who are familiar with electromagnetic theory and measurement techniques [4]. The recommendation SAR limited by the International Commission of Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronics Engineers (IEEE) [4] is 2 W/kg averaged over ten (10) gram of tissue and Federal Communication Commissions (FCC) allowed 1.6 W/kg in 1 g of head tissue [5, 6]. This guideline is for limiting the electromagnetic fields exposure for public safety.

The exposure depends on many parameters such as frequency [6], source location, electromagnetic field structure, types of tissues and also the signal and channel time occupancy [6, 7]. For measuring the exposure, the mobile phone will be tested by using the specific anthropomorphic mannequin (SAM) phantom. SAM phantom is designed in specific shape and material to produce the actual peak spatial-average SAR estimation that found in the head tissue of person while mobile phone used in normal [8].

In this project, the value of SAR is obtained at different distance between Planar Invertered-F Antenna (PIFA) and European Cooperation in the Field Scientific and Technical Research (COST) 244 spherical head model by using Computer Simulation Technology (CST) Microwave Studio. Furthermore, the characteristics performance of designed antenna also is taking into account. The proposed antenna operates at two frequency bands which are commonly use today in the applications of Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS). The coverage are GSM900 (880-960MHz) and GSM1800/1900/UMTS2500 (l710-2690MHz).

1.2 Problem statements

Nowadays, the recent mobile phone does not only used in voice application [7] but also served in many kinds of applications. Therefore it operates in different protocols and frequency bands [7]. So, no wonder if the concern of possible health effects due to electromagnetic field exposure has come to public knowledge since mobile phone became a necessity of life instead of just desire to have one [9]. The evaluation of power absorption by the human body is important not only for the potential hazard problem but also for the research [10] and antenna design of mobile phone because of it is used near to the human body. In addition, there are bad effect occurred on the humans and surroundings in long term by exposure of EMF. The World Health Organization (WHO) reports that in developed countries, everyone includes child are exposed to the EM field in their home, office, school, during travel and in social activities [11]. Based on these cases, the radiation can effect not limited to acute electrical injury such as brain tumors, acute leukemia, prenatal exposure and non-carcinogenic effects but also contribute to a heat effect in the microwave region which is generated by absorption energy [4]. These effects should be studied and considered by responsible party.

As an investigation, several studies have been done to investigate the maximum value of SAR. The planar inverted-F antenna (PIFA) is chosen as an antenna to obtain its efficiencies and SAR value at different distances. PIFA is selected because it is the most embedded antenna in mobile phone currently. The small and low profile [12-15] of characteristic make it suitable for mounting on mobile equipment [1, 2] thus it can be the promising antenna types. The high degree of sensitivity in vertically and horizontally polarized radio wave [1, 2] also makes it suited in mobile applications. As an advantage, PIFA has relatively smaller backward radiation toward the user so that can reduce the possible electromagnetic energy absorption by the mobile handset user’s head. The parameters of the PIFA is given by the equation [12, 13]

$$f = \frac{c}{4\,(L+W)} \tag{1.1}$$

Where f is frequency operation, c is the free space velocity of light $(3 \times 10^8\ m/s)$ and $L + W = x$ is the total length *(m)*. The other advantages of PIFA are easy fabrication, low manufacturing cost [12-15], simple structure [14] and with light weight [13, 15].

SAR is then evaluated by using COST244 spherical model at different distances. The characteristics of COST244 spherical model are similar to the SAM phantom, at 900 MHz are the relative permittivity, ε_r = 41.5 and conductivity, σ = 0.97 S/m, at 1800 MHz are the relative permittivity, ε_r = 40.0 and the density, ρ = 1000 kg/m^3. The SAR equation is given by [4, 9];

$$SAR = \frac{\sigma}{\rho} E^2 \tag{1.2}$$

Where E is induced electric field (V/m), ρ is the density of tissue (kg/m^3) and σ is the electrical conductivity of tissue (S/m). SAR is expressed in units of W/kg.

1.3 Project objectives

The objectives of this project are to:

a) Develop PIFA and COST244 spherical head model which is specifically can be used in two frequencies; 900 MHz and 1800 MHz.

b) Simulate the SAR value at 1 g and 10 g average mass at difference distances.

c) Analyse the influence of the distance between the PIFA and the COST244 spherical head on the SAR induced in the head.

1.4 Project scopes

There are some limitations that need to be considered in this project:

a) The result of antenna characteristics and SAR values are in the limitation of 900 MHz and 1800 MHz frequency band.

b) The simulation of SAR in the distances of less than 15 mm between PIFA and the COST244 spherical head model.

c) The analysis only focuses on the PIFA designed.

CHAPTER 2

LITERATURE REVIEW

This chapter describes about the theory related to this project including EMF radiation, SAM phantom, COST244 spherical head model, SAR, PIFA, and related research. There are also the explanations about the effects of EMF in the community, advantages of antenna chosen and SAR simulation techniques.

2.1 Electromagnetic field radiation

The oscillated electric and magnetic forces carries electromagnetic field and radiation. The rough division is static and low frequency starting from 0 to 10 kHz, high frequency or radiofrequency from 10 kHz to 300 GHz [4], optical waves such as infrared, visible light and ultraviolet. Then, it is followed by X-ray and gamma rays. Figure 2.1 shows the spectrum of frequency which summarises the division of frequency. This work only focused on radio waves and microwave from 900 MHz to 1800 MHz.

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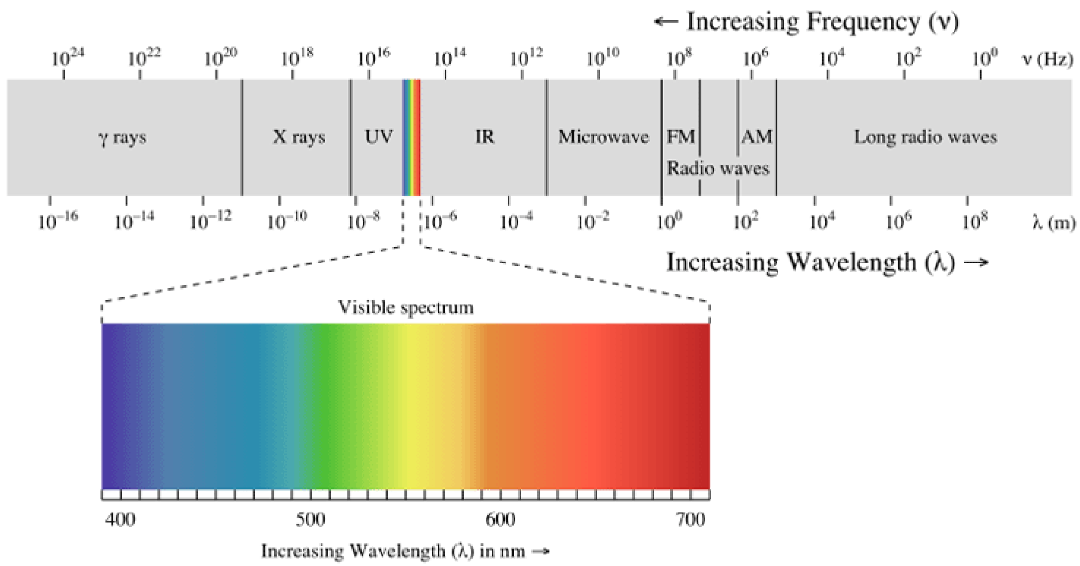

Figure 2.1: The division of frequencies.

2.1.1 The effects of EMF exposure

The effects of EMF radiation [16] can be divided into two groups. Those are in short term and long term effects. Short term effect can be defined as a direct observable or measurable effect during exposure or within a few hours or a day after exposure to a physical agent. It is also called as deterministic effects. The effect of the agent is predicted on a specific individual such as a red skin after exposure to sunlight, a burn due to microwaves and feeling electricity. It also characterised by threshold. The worst of short term effect is proportional to energy rate. For example to feel current, a certain threshold must be exceeded and the more intense the current the more nerves pulse are generated. The feel of microwave on the skin starts at a power density giving temperature increase of about 1°C.

Therefore for long term effect, it can be obtained by statistical, stochastic or probabilistic effects. Some effects appear after a long period of time likes after month or many years. The probabilistic effects also known as low level effect because never occurred on short term effects and the uncertainties is due to the exploration of animal studies and results of epidemiological studies. Probabilistic effects can only predict a probability of an effect on a specific of individual. This probability that increase with energy is used as risk assessment [16].

Electromagnetic fields are biologically active in animals and humans and cause discomfort and disease [17]. Specifically radio frequency (RF) radiation from mobile phone can increase risk for brain [17] cancer, affections on auditory system, burning sensation, heating in ear region [18], and changes in behaviour and memory loss [19].

In RF, EMF is divided into four ranges [16] of human body's absorption energy. Table 2.1 shows the frequency range of RF in terms of human body's absorption energy.

Table 2.1: The frequency range of RF in human body's absorption energy [16].

Frequency range	**Absorption area**
100 kHz - 20 MHz	Trunk
20 MHz – 300 MHz	Whole body, partial body as head
300 MHz - several GHz	Significant local and non-uniform absorption occurs
10 GHz and above	Body surface

2.1.2 The limitation of EMF exposure

In general public, there are individuals of all ages with their health status. Some peoples do not aware about the EMF exposure occurred on them. In addition, they also do not take any precautions in order to reduce the exposure. Based on this considerations, ICNIRP have provides some restrictions and reference level depending on frequency. The physical quantities specified are current density, SAR and power density [19]. The reference level on the physical quantity cannot be exceeded for protection. If value measured is exceeded from the reference level, the restriction cannot be followed.

Micheal H. Repacholi in ICNIRP guidelines [16] considered the development of safety factors for high frequency. Those are:

a) Effect of EMF exposure under severe environmental conditions and high activity levels

b) The potentially higher thermal sensitivity in certain population groups such as frail or elderly, infants and young children and people with disease or taking medications that compromise thermal tolerance.

The additional factor of reference level for high frequency levels are:

a) Differences in absorption of electromagnetic energy by individuals of different sizes and different orientations relative to the field.

b) Reflection, focusing and scattering of incident field which can result in enhanced localized absorption of high frequency energy.

There are three predominant [20] frequency ranges exposed by EMF. Table 2.2 summarizes the frequency range based on its sources.

Table 2.2: The sources of frequencies.

Frequency range	**Sources**
Extremely Low Frequency (ELF): 0-300 Hz	• Magnetic Resonance Imaging (MRI) • Industrial use of direct current for electrolysis
Intermediate Frequency (IF): 300 Hz-10 MHz	• Computer monitors • Industrial process • Security system
Radio Frequency (RF, microwaves): 10 MHz-300 GHz	• Radar • Radio • Television broadcast • Telecommunications

ICNIRP also has arranged the basic restriction based on frequency range. Table 2.3 shows the frequency range based on basic restriction [19] and its prevention.

Table 2.3: The basic restrictions and prevention.

Frequency range	**Basic restriction**	**Prevention**
1 Hz-10 MHz	Current density	• Nervous system function
100 kHz-10 GHz	SAR	• The whole body heat stress • Excessive localized tissue heating
10 GHz-300 GHz	Power density	• Excessive heating in tissue at or near the body surface

Moreover, the basic restrictions for current densities, whole body averaged SAR and localized SAR for frequencies between 1 Hz to 10 GHz. There are also specifications for general public exposure. Table 2.4 shows the specifications of general public exposure.

Table 2.4: The general public exposure's restrictions.

Frequency range	**Current density for head and trunk (mA m^{-2}) (rms)**	**Whole body average SAR (W kg^{-1})**	**Localised SAR (head and trunk) (W kg^{-1})**	**Localised SAR (limbs) (W kg^{-1})**
Up to 1 Hz	8	-	-	
1-4 Hz	8/f	-	-	-
4 Hz-1 kHz	2	-	-	-
1-100 kHz	f/500	-	-	-
100 kHz-10 MHz	f/500	0.8	2	4
10 MHz-10 GHz	-	0.8	2	4

2.2 EMF absorption measurement

2.2.1 Specific absorption rate

The electromagnetic fields or wave exposed caused the electromagnetic energy to be induced or deposited. The fields are forces that act only with electric charges. The absorbed electromagnetic energy in the living body causes effects depending on parameters such as energy (dose), energy rate (dose rate), field strength, the frequency (photon energy) of the fields and also the type of tissue. The calculation of absorbed energy is called as specific absorption rate (SAR) and is given by equation (1.1). With σ is the effective conductivity of the material, ρ is the density in kg/m^3 and E is the electric field strength [1, 4, 9, 21 – 25]. This energy disturbs in general physical and chemical changes but always produces the physical effects of an increase of molecular motion. It can be shown that heat in the material causing a rise in temperature but chemical effects still can be dominated so that the rise in temperature can be very small. Therefore, the level of SAR should be moderate to avoid direct cumulative effects, blistering and burns.

SAR is a function to evaluate the near field [4] of EMF radiation from mobile phone. It is evaluated in cubic volume. Figure 2.2 shows a cube around the point expands in isotropic directions along the coordinate system until it contains 1 g or 10 g tissue [5]. SAR can be estimated by numerical simulation or experimental evaluation.

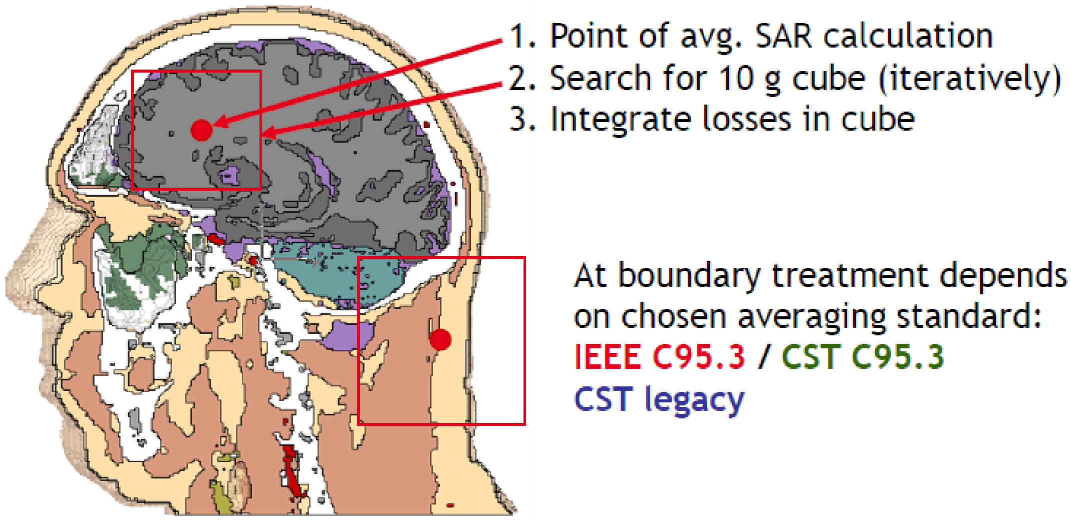

Figure 2.2: The averaging procedures of SAR [5, 24].

FCC has sets the parameters and procedures for SAR measurement [6, 14]. When the SAR testing is lower than the level reference or less than the limitations provided; the device is in pass grade. Each measurement especially every model of mobile phone is at maximum transmit power and being tested under the number of different scenarios and conditions.

2.2.2 Temperature of cell

The increasing temperature in tissue during the initial transient period of RF energy absorption is linearly proportional to the value of SAR. The rate of initial rise in temperature can be related to SAR through the following equation:

$$SAR = \frac{c\Delta T}{\Delta t} \tag{2.1}$$

Where c is the specific heat capacity of tissue (J/kg°C), ΔT is the temperature increment in °C and Δt is a short duration in seconds, s over which ΔT is measured [4, 22, 26].

2.2.3 Biological hazards of electromagnetic fields

The hazardous of EMF can be divide into two groups, those are:

a) Thermal effect

b) Non-thermal effect

Thermal effect can effect on the eye, skin and brain tissue [16, 17]. For example, the exposure of rabbit eye to the incident power in high densities likes 100 mW/cm^2 in half an hour. The quantity of densities and the interval of time can induce lens opacification that is cataract. The effects appeared after a few days with the increasing temperature of 3°C. Rabbit eye is taken into account because of it is very similar to the human eye. Figure 2.5 briefs the threshold that gives the thermal effect on several part of human body.

Table 2.5: The threshold for the induction of thermal effects to the human body.

Target	**Effect**	**Threshold**
Whole body	Various physiological effects	1.0 °C
Eye lens	Cataract	3 ÷ 5°C
Skin	Warmth sensation	0.02 ÷ 1°C
	Pain sensation or burns	10 ÷ 20°C
Brain	Neuron damage	4.5°C

The sign of division, ÷ in Table 2.5 shows the difference of range from that value. For non-thermal effect, on cell there might be deoxyribonucleic acid (DNA) damages, effects on embryo development and cancer promotion. Therefore for the animal, the possibility is effecting on DNA in brain cells, the blood-brain barrier and on the central nervous system. There is still have negative answer on these findings but some positive in general means not been replicated.

2.3 Human head model

2.3.1 Standard Anthropomorphic Mannequin

Standard Anthropomorphic Mannequin (SAM) [5, 8, 9, 25, 27] is a two layered head phantom that is used for the measurement of mobile phone's exposure and also for antenna pattern testing. SAM is used because of live human head cannot be safely instrumented for measurement [16], therefore SAR will be estimated by computer simulation and testing with phantom heads. Figure 2.3 shows the SAM phantom.

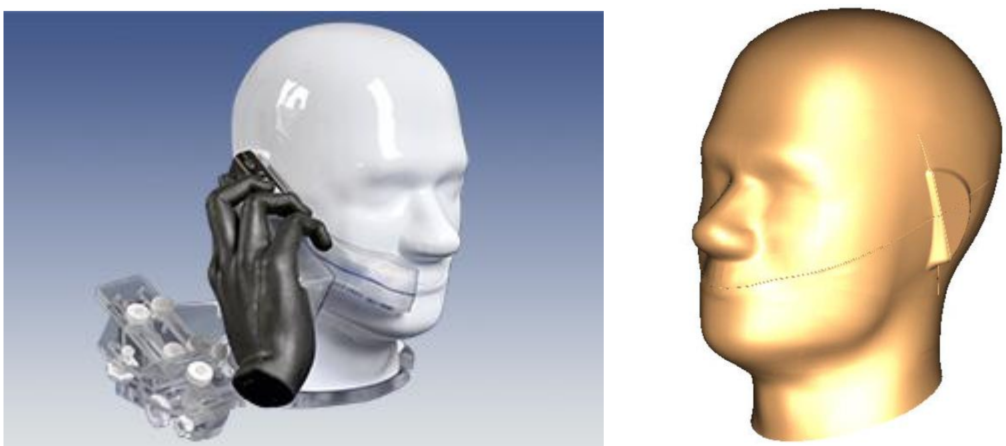

Figure 2.3: The SAM phantom.

SAM was developed by IEEE Standards Coordinating Committee 34, Sub Committee 2, Working Group 1 (SCC34/SC2/WG1) [26] for the purpose of developing the recommendation practice of determining SAR in the head through measurement techniques. Then, it is used by European Committee for Electrical Standardization (CENELEC), International Electrotechnical Commission, Association of Radio Industries and Businesses and Federal Communications Commission (FCC) [9, 26].

It is a lossless plastic shell and ear spacer which is filled with a homogeneous fluid that has the average electrical properties of head tissue at the test frequency. SAM phantom simulation has the ability to estimate SAR in adult and children [8]. Figure 2.4 shows the example of SAR simulation by using SAM phantom.

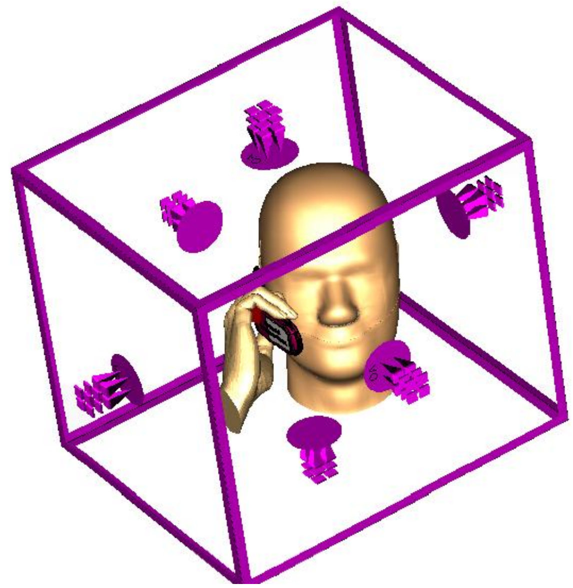

Figure 2.4: The simulation SAR with SAM head by using CST Microwave Studio.

2.3.2 COST244

COST244 is a homogeneous dielectric sphere or cube [28]. These two kinds [29] of phantom have the dimension of 200 mm in a side for cube [3, 30] and the radius of the sphere is 100 mm. The electrical properties of the COST244 are slightly the same as SAM head phantom where its relativity and conductivity depend on frequency.

The phantom is homogeneous and solid. It consists of Agar, TX-151, polyethylene powder, sodium azide, sodium chloride and deionised water [28]. Table 2.6 shows the percentage example of each component that realizes the relative permittivity at frequency of 1.5 GHz.

Table 2.6: The percentage of each component that realizes the relative permittivity at frequency of 1.5 GHz.

Ingredients of the human head equivalent phantom	**Percentage**
Polyethylene powder	13.3 %
Deionised water	82.2 %
Agar	2.55 %
TX-151	1.4 %
Sodium azide	0.05 %
Sodium chloride	0.5 %

2.4 Antenna

Antenna is a device that being used for transforming the guided electromagnetic signal into electromagnetic waves. An antenna is basically transducer that converts electric current into electromagnetic waves and vice versa [31] and comes in many different structures, shapes and sizes. The size of antenna is much related to the wavelength operation of the antenna. The electromagnetic signal and electromagnetic waves are propagating in free space. Usually several characteristics are taken while simulating and measuring the antenna such as radiation pattern, return loss, gain, voltage standing wave ratio (VSWR) and SAR.

2.4.1 Planar inverted-F antenna

Most mobile phone is embedded with planar inverted-F antenna (PIFA). It is small and has a low profile making it suitable for mounting on portable equipment. Besides a high degree of sensitivity to both vertically and horizontally polarized, it can reduce the possible electromagnetic energy absorption by the mobile phone user's head because of relatively smaller backward radiation toward user [1, 2]. PIFA consist of [14-16, 32] five basic elements, these are

i. A large metallic ground plane
ii. A resonating metallic plane
iii. A substrate separating the two planes
iv. A shorting pin
v. A feeding mechanism

For designing the PIFA, the operating frequency is inversely proportional to the physical dimension. For microstrip patch antenna, the calculation theory for length of the antenna patch is:

$$L \approx \frac{\lambda_D}{4} = \frac{1}{4}\frac{c}{f\sqrt{\varepsilon_r}} \qquad (2.2)$$

$$W = \frac{c}{4f}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (2.3)$$

where L is the length, W is the width and λ_D is the wavelength in the substrate. The feeding is located at a point on the patch. The exact position can be calculated by the following equation.

$$\lambda_o = \frac{c}{f_r} \qquad (2.4)$$

Figure 2.5 shows the dimension of PIFA. Figure 2.6 shows the example of PIFA implemented on a circuit. The shorting mechanism of PIFA are shorting pin, shorting plate and shorting plate together with shorting pin [14-16].

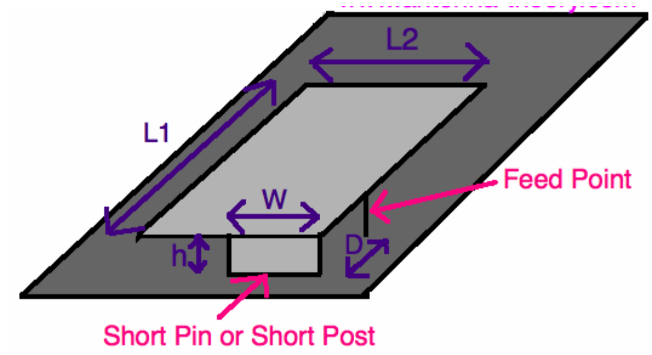

Figure 2.5: The dimension of PIFA.

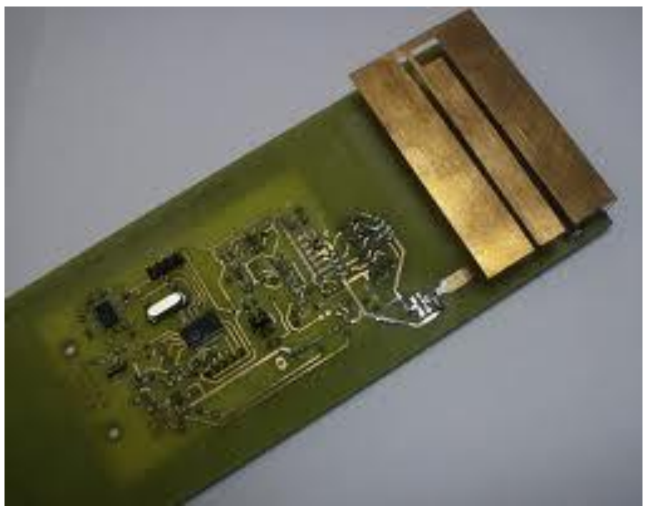

Figure 2.6: PIFA implementation (Panagiotas Broutas, 2011).

2.4.2 Radiation pattern

Radiation pattern is the properties of antenna radiation displayed in the function of spherical coordinates, (θ,ϕ). The visualization can be in rectangular form or polar form. Mostly, the radiation pattern is determined in the far-field region for constant distance and frequency. Then, the radiation pattern will be characterized by a main beam with 3-dB beamwidth. There are several shapes of radiation pattern obtained from different dimension by [31-32]. Figure 2.7 - Figure 2.8 show the variety of PIFA radiation pattern in 2-dimension and 3-dimension.

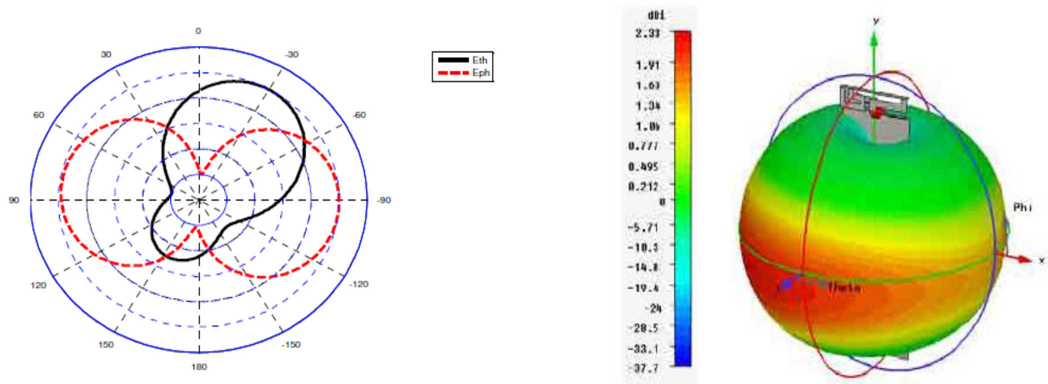

Figure 2.7: The PIFA radiation pattern at range of 850-950 MHz [14].

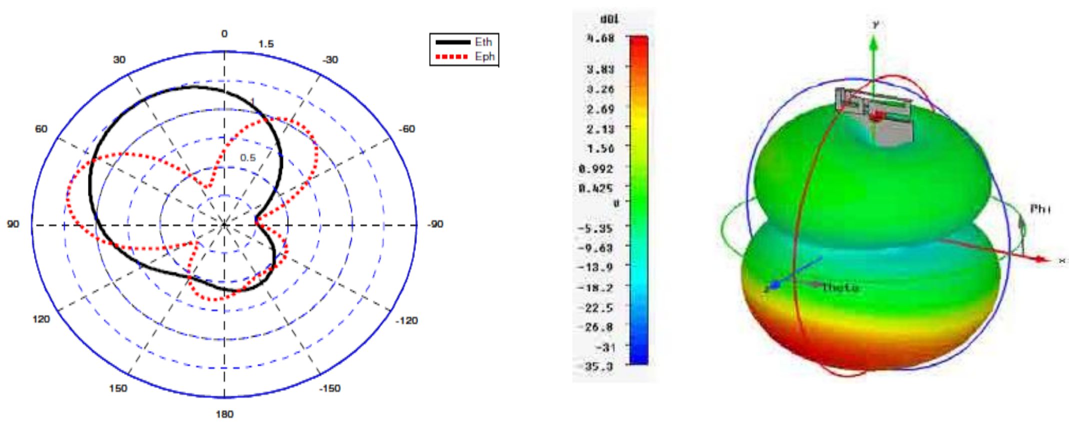

Figure 2.8: The PIFA radiation pattern at 1800 MHz [14].

2.4.3 Return loss

Return loss is a measurement of the effectiveness of power delivery from a transmission line to a load. The best result for return loss is lower than -20 dB. Figure 2.9 shows the return loss that should be resulted by PIFA at 900 MHz and 1800 MHz [14].

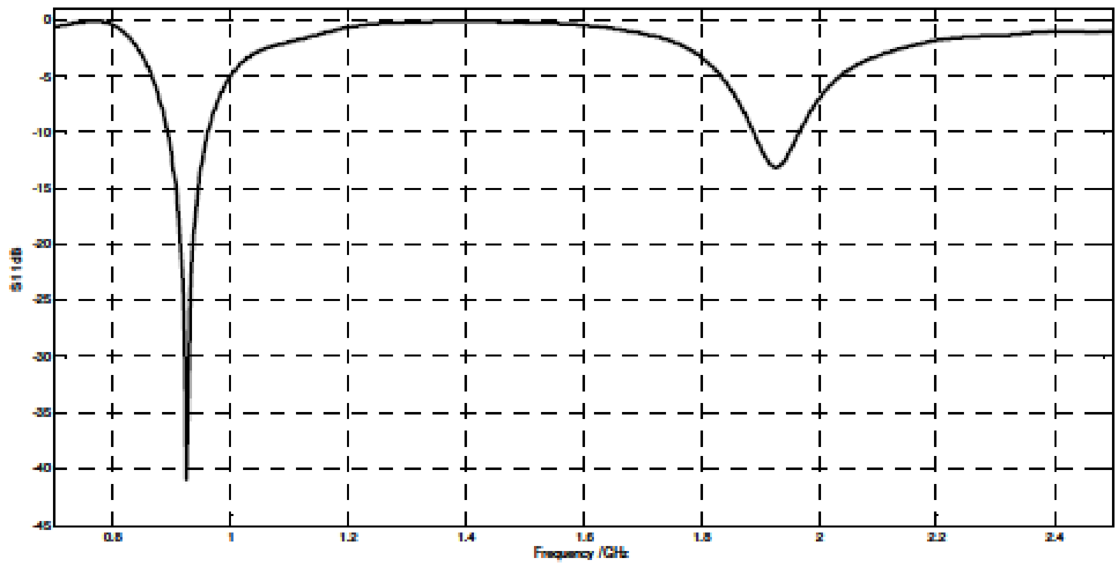

Figure 2.9: The return loss in 900 MHz and 1800 MHz.

2.4.4 Gain

The gain of an antenna in a direction is the amount of energy radiated in that direction compared to the energy an isotropic antenna would radiate in the same direction when driven with the same input power [31]. Antenna with a large aperture has more gain which means it captures more energy from a passing radio wave. Gain is given by following equation.

$$G = 10\log 10\left(\eta \frac{4\pi}{\lambda^2} A\right) \tag{2.5}$$

Where η is the efficiency of antenna.

2.4.5 VSWR

VSWR is a measure of impedance mismatch between the transmission line and antenna. A VSWR of 1:1 indicates a perfect match while a VSWR of ∞:1 indicate the worst case [33].

2.5 Previous method

2.5.1 Simple Evaluation Method of Estimating Local Average SAR

The aim of this work is to realize the estimation of the local average SAR calculated by the measured SAR using the thermal technique and to investigate the limit of the simplification of the measurement point for averaging [3]. The limitation of simplification is investigated when four types of antennas which are a half-wave dipole antenna, a monopole antenna mounted on a metal box, a planar inverted F antenna and a half-wave dipole antenna with a planar reflector are close to the COST244 cubical and spherical head model at 900 MHz and 2 GHz. Then, the affect of the distance and frequency of the average SAR using the proposed method is investigated.

The dimension of the cube 200 mm in a side and the radius of the sphere is 100 mm. Table 2.7 shows the characteristics of head model. The density, ρ of the head model is 1000 kg/m^3. Table 2.8 shows the reference value of the local 10-g average SAR when d is varied. Figure 2.10 shows the local 10-g average SAR in the cubical model when d is varied from 5 to 25 mm. This is one of the result obtained. From the result, the deviation of the local 10-g average SAR using proposed method is within ±10% when d is larger than 10 mm at 900 MHz.

Table 2.7: The characteristics of head mode.

Frequency	**Electrical properties**	
	Relative permittivity, ε_r	**Conductivity, σ (S/m)**
900 MHz	41.5	0.97
2 GHz	40.0	1.40

Table 2.8: Reference value of the local 10-g average SAR by using of the half-wave dipole antenna when d is varied from 5 to 25 mm.

d (mm)	**SAR_{10g} (W/kg)**
5	9.38
10	8.33
15	6.76
20	5.34
25	4.08

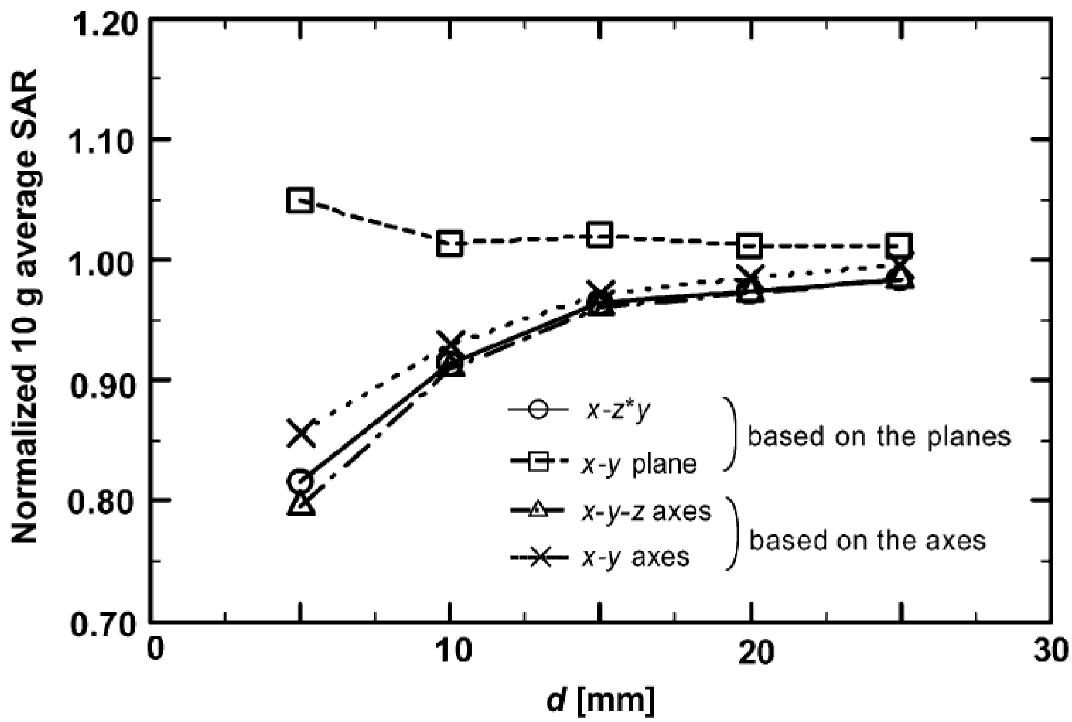

Figure 2.10: Normalised 10-g average SAR versus *d* at 900 MHz.

2.5.2 Analytical Calculation of the Specific Absorption Rate from Cellular Phone in Some Realistic Situations

This research work is to determine the SAR in a spherical model head irradiated by an incident EM wave from a wire antenna and compare the local SAR distribution for different scenarios [6]. The human head is characterized by a dielectric constant depending on the position point located at the distance and a conductivity distribution. Figure 2.11 shows the calculated normalized SAR in a homogeneous sphere for *d* = 1 mm.

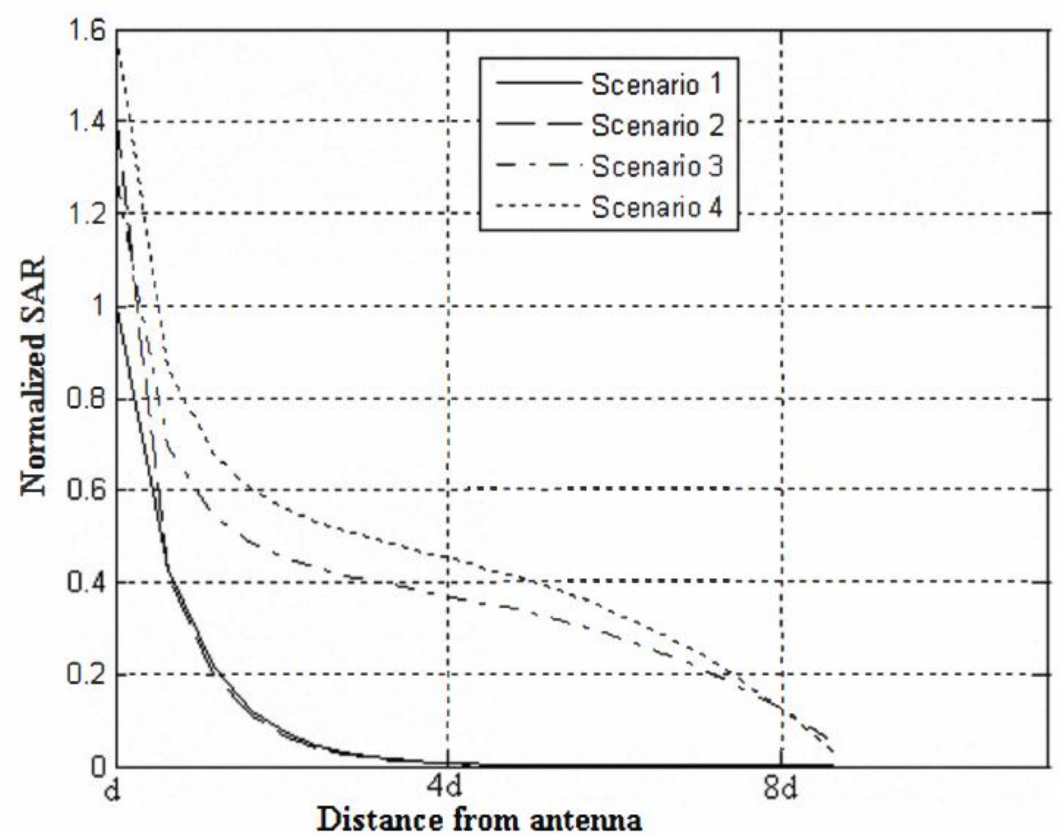

Figure 2.11: The calculated normalized SAR in a homogeneous sphere for *d* = 1 mm.

2.5.3 Analysis of Power Absorption by Children's Head as a Result of New Usages of Mobile Phone

The location of the source is a fundamental parameter since the exposure not only depends on the power emitted but also on the distance and the orientation of the sources [7]. One of the result can be obtained is the influence of the distance between mobile phone and the head on the SAR induced in the head. Different distances have been considered between the mobile and the head where distance, *d* is at 2.5, 10, 14, 18 and

40 cm. Table 2.9 shows the radiated power induced in the child head model of 9 years old for each mobile phone model and for each distance. The SAR over 10 g and SAR contiguous values decrease when distance increases. Figure 2.12 shows the normalized peak SAR to the maximum SAR induced in the head at *d*=2.5 cm for each mobile and for each distance.

Table 2.9: The radiated power induced in the head at d= 2.5 cm for each distance in the child head model at 900 MHz and 835 MHz.

Distance (cm)	**2.5**	**10**	**14**	**18**	**40**
Mobile phone at 835 MHz	1.0	0.152	0.098	0.071	0.018
Mobile phone at 900 MHz	1.0	0.129	0.082	0.061	0.027

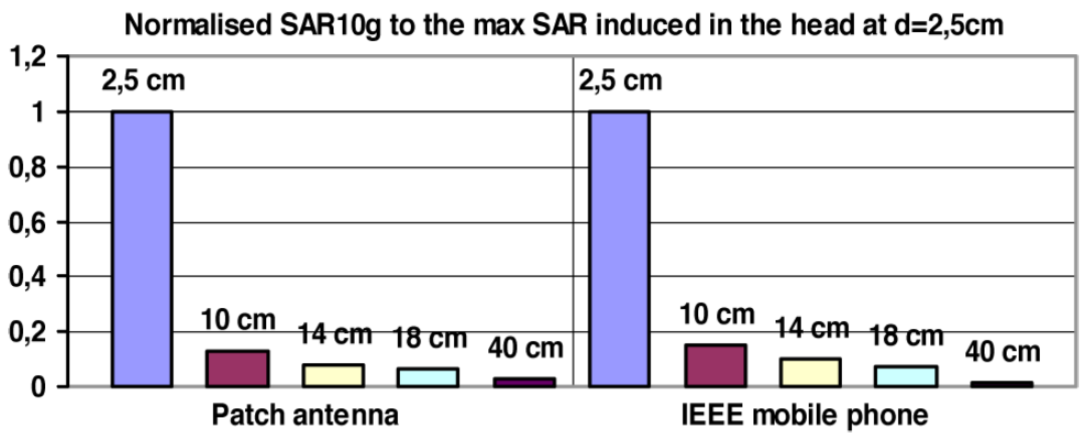

Figure 2.12: The normalized peak SAR to the maximum SAR induced in the head at d=2.5 cm for each mobile and for each distance.

2.5.4 900 MHz and 1800 MHz Mobile Phone Effect Towards Adult Head in SAR Distribution and SAR in Weight

The objective of this paper is to investigate the effects of 900 MHz and 1800 MHz mobile phone towards adult health in SAR distribution, SAR 1 g and 10 g weight [34]. This paper concentrates on adult head brain tissue with relative permittivity 45.8055 F/m and the radiated power of monopole antenna is 0.6 W. The distance of the phone and head model is 10 mm. Table 2.10 shows the total absorbed power and SAR values for 900 MHz and 1800 MHz associated with SAR.

Table 2.10: The total absorbed power and SAR values for 900 MHz and 1800 MHz associated with SAR.

Frequency (MHz)	**SAR distribution (W/kg)**	**SAR for 1 g weight (W/kg)**	**SAR for 10 g weight (W/kg)**
900	0.117958	0.000116735	0.00116735
1800	0.0467406	4.69726×10^{-5}	0.000469726

2.5.5 Hybrid Computational Scheme for Antenna-Human Body Interaction

A COST244 model is adopted as a human phantom [35] represents a homogeneous cubical human head of size 200 x 200 x 200 mm^3. The relative permittivity, ε_r is 41.5, conductivity, σ is 0.95 S/m and volume density, ρ is 1000 kg/m^3. Then a 160 mm long half-wavelength dipole at 900 MHz is used as a radiation source with input power of 250 mW. The distance between the antenna and the human head is 15 mm. Figure 2.13 shows the variations of the unaveraged SAR along the y-axis with and without subgridding.

REFERENCES

1. Saidatu, N.A.; Soh, P.J.; Sun, Y.; Lauder, D.; Azremi, A.A.H.; , "Multiband Fractal PIFA (Planar Inverted F Antenna) for mobile phones," *Wireless Communication Systems (ISWCS), 2010 7th International Symposium on* , vol., no., pp.671-675, 19-22 Sept. 2010.

2. Saidatul, N.A.; Azremi, A.A.H.; Ahmad, R.B.; Soh, P.J.; Malek, F.; , "A development of Fractal PIFA (planar inverted F antenna) with bandwidth enhancement for mobile phone applications," *Antennas & Propagation Conference, 2009. LAPC 2009. Loughborough* , vol., no., pp.113-116, 16-17 Nov. 2009.

3. Kawai, H.; Ito, K.; , "Simple evaluation method of estimating local average SAR," *Microwave Theory and Techniques, IEEE Transactions on* , vol.52, no.8, pp. 2021- 2029, Aug. 2004.

4. "IEEE Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head From Wireless Communications Devices: Measurement Techniques," *IEEE Std 1528-2003* , vol., no., pp.0_1-149, 2003.

5. Nan Qi; Min Zhang; Wittig, T.; Prokop, A.; , "Application of CST time domain algorithm in the electromagnetic simulation standard of the SAR for mobile phone," *Microwave and Millimeter Wave Technology, 2008. ICMMT 2008. International Conference on* , vol.4, no., pp.1717-1720, 21-24 April 2008.

6. Rajhi, A.; Gharsallah, A.; Gharbi, A.; , "Analytical calculation of the specific absorption rate from cellular phone in some realistic situations," *Electromagnetic Compatibility (APEMC), 2010 Asia-Pacific Symposium on* , vol., no., pp.1641-1644, 12-16 April 2010.

7. Hadjem, A.; Conil, E.; Gati, A.; Man-Faï Wong; Wiart, J.; , "Analysis of Power Absorbed by Children's Head as a Result of New Usages of Mobile Phone," *Electromagnetic Compatibility, IEEE Transactions on* , vol.52, no.4, pp.812-819, Nov. 2010.

8. Ae-Kyoung Lee; Jaehoon Yun; , "A Comparison of Specific Absorption Rates in SAM Phantom and Child Head Models at 835 and 1900 MHz," *Electromagnetic Compatibility, IEEE Transactions on* , vol.53, no.3, pp.619-627, Aug. 2011.

9. S. H. Ronald, M. F. A. Malek, S. I. S. Hassan, C. E. Meng, M. H. Mat, M. H. Zulkefli, S. F. Maharimi, Designing Asian-sized Hand Model for SAR Determination at GSM 900/1800: Simulation Part, *Progress in Electromagnetics* Research, vol.129: pp. 439-467, 2012.

10. Yoshioka, H.; Qian Chen; Igari, K.; Sawaya, K.; , "Measurement of power absorption by COST 244 human head model by using pattern integration method," *Electromagnetic Compatibility, 1999 International Symposium on* , vol., no., pp.333-336, 1999.

11. Juan Antonio Ortega-Garcia, Marlene Martin, Enrique Navarro-Camba, Julia Garcia-Castell, Offie P. Soldin, Josep Ferris-, Pediatric Health Effects of Chronic Exposure to Extremely Low Frequency Electromagnetic Fields, *Current Pediatric Review,*: pp. 234-240, 2009.

12. Sun, J.S. and S.Y. Huang, A small 3-D Multiband Antenna of "F" Shape for Portable Phones' Applications, *Progress in Electromagnetics Research Letters*, vol.9, pp. 183-192, 2009.

13. Mat, M.H.; Malek, F.; Ronald, S.H.; Zulkefli, M.S.; , "A comparative study of simple geometrical head phantoms on specific absorption rates for simulations and measurements at 900MHz," *Biomedical Engineering (ICoBE), 2012 International Conference on* , vol., no., pp.330-334, 27-28 Feb. 2012.

14. Byung Chan Kim; Ju Derk Park; Hyung Do Choi; , "Tapered type PIFA design for mobile phones at 1800 MHz," *Vehicular Technology Conference, 2003. VTC 2003-Spring. The 57th IEEE Semiannual* , vol.2, no., pp. 1012- 1014 vol.2, 22-25 April 2003.

15. Chen, H.-M.; Lin, Y.-F.; Cheng, P.-S.; Lin, H.-H.; Song, C.T.P.; Hall, P.S.; , "Parametric study on the characteristics of planar inverted-F antenna," *Microwaves, Antennas and Propagation, IEE Proceedings* , vol., no., pp. 534- 538, 9 Dec. 2005.

16. Protection, I.C.o.N.-I.R., *ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields.* 1998.

17. Kapetanakis, T.N.; Kaprana, A.; Vardiambasis, I.O.; Ioannidou, M.P.; , "Estimation of exposure time to GSM-900 radiation causing auditory brainstem response changes in rabbits using neuro-fuzzy system," *Microwaves, Communications, Antennas and Electronics Systems (COMCAS), 2011 IEEE International Conference on* , vol., no., pp.1-2, 7-9 Nov. 2011.

18. De Santis, V.; , "Ear Temperature Increase Produced by Cellular Phones Under Extreme Exposure Conditions," *Microwave Theory and Techniques, IEEE Transactions on* , vol.60, no.6, pp.1728-1734, June 2012.

19. Bottauscio, O.; Chiampi, M.; Zilberti, L.; , "Accuracy of SAR Reconstruction in Human Phantoms From Surface Field Values," *Magnetics, IEEE Transactions on* , vol.47, no.11, pp.4617-4622, Nov. 2011.

20. Repacholi, M.H., An Overview of WHO's EMF Project and the Health Effects of EMF Exposure, *Proceedings of the International Conference on Non-Ionizing Radiation at UNITEN 2003*, pp.1-21.

21. Priyadarshini, S.J.; Mary, T.A.J.; Sugumar, D.; Ravichandran, C.S.; , "Impact of SAR on human head modeling in Elevators using IFA," *Applied Electromagnetics (APACE), 2010 IEEE Asia-Pacific Conference on* , vol., no., pp.1-5, 9-11 Nov. 2010.

22. Lin, J.C.; , "International Guidelines for Radio-Frequency Exposure, Especially for the Most Successful Application of Electromagnetics in Medicine: Magnetic Resonance Imaging [Telecommunications Health & Safety],"*Antennas and Propagation Magazine, IEEE* , vol.53, no.1, pp.169-174, Feb. 2011.

23. Buleandra, A.; Petrescu, T.; , "SAR calculations inside a heterogeneous human heart model," *Software, Telecommunications & Computer Networks, 2009. SoftCOM 2009. 17th International Conference on* , vol., no., pp.15-18, 24-26 Sept. 2009.

24. Wittig, T., *Bio-Effects of Mobile Phone.* 2009.

25. Mat, M.H.; Malek, F.; Ronald, S.H.; Zulkefli, M.S.; , "A comparative study of simple geometrical head phantoms on specific absorption rates for simulations and measurements at 900MHz," *Biomedical Engineering (ICoBE), 2012 International Conference on* , vol., no., pp.330-334, 27-28 Feb. 2012.

26. Lin, J.C.; , "Specific absorption rates (SARs) induced in head tissues by microwave radiation from cell phones," *Antennas and Propagation Magazine, IEEE* , vol.42, no.5, pp. 138- 139, Oct 2000.

27. Beard, B.B. and W. Kainz, *Review and Standardisation of Cell Phone Exposure Calculations Using the SAM Phantom and Anatomically Correct Head Models.* BioMedical Engineering Online, 2004.

28. Qiang Chen; Yoshioka, H.; Igari, K.; Sawaya, K.; , "Measurement of radiation efficiency of antennas in the vicinity of human head model proposed by COST 244," *Antennas and Propagation Society International Symposium, 1999. IEEE* , vol.2, no., pp.1118-1121 vol.2, Aug 1999.

29. Ito, K.; Okano, Y.; Hase, A.; Ida, I.; , "A tissue-equivalent solid phantom for estimation of interaction between human head and handset antenna," *Antennas and Propagation for Wireless Communications, 1998. 1998 IEEE-APS Conference on* , vol., no., pp.89-92, 1-4 Nov 1998.

30. Ito, K.; Okano, Y.; Hase, A.; Asahina, T.; Yoshimura, H.; , "A study on solid phantoms for estimation of interaction between human body and electromagnetic waves," *Electromagnetic Compatibility, 1999 International Symposium on* , vol., no., pp.337-340, 1999.

31. Wade, P., *Antenna Fundamentals.* 1998.

32. Luhaib, S.W., K.M. Quboa, and B.M. Abaoy, *Design and Simulation Dual-Band PIFA Antenna for GSM System.* 2012-9th International Multi-Conference on Systems, Signals and Devices, 2012.

33. Kutter, R.E., *Fractal Antenna Design.* Thesis University of Dayton, 1996.

34. Lias, K.B.; Abidin, W.A.W.Z.; Masri, T.; Bin Othman, A.-K.; Marzuki, A.S.W.; Mat, D.A.A.; Kipli, K.; , "900MHz and 1800MHz mobile phone effect towards adult head in SAR distribution and SAR in weight," *Systems Man and Cybernetics (SMC), 2010 IEEE International Conference on* , vol., no., pp.2239-2242, 10-13 Oct. 2010.

35. K. N. Ramli, R. A. Abd-Alhameed, C. H. See, P. S. Exell and J. M. Noras, Hybrid Computational Scheme for Antenna-Human Body Interaction, *Progress in Electromagnetics Research*, Vol. 133, pp. 117-136, 2013.

36. Seddik Bri, Samira Kassimi, Mohamed Habibi, *Specific Absorption Rate (SAR) Distribution in the Human Head at Global System Mobil (GSM) Frequencies.* European Journal of Scientific Research, 2011: pp. 590-600.

37. Faruque, M.R.I., M.T. Islam, and N. Misran, *Assessment of Different Types of Human Head Shape and Ear Effects for Portable Telephone Exposure on EM Exposure.* 2011: pp. 130-139.

38. Lazarescu, C.; Nica, I.; David, V.; , "SAR in human head due to mobile phone exposure," *E-Health and Bioengineering Conference (EHB), 2011* , vol., no., pp.1-4, 24-26 Nov. 2011.

39. Kin Lu Wong, "*Compact and Broadband Microstrip Antennas*", John Wiley & Sons, New York, 2002, pp. 78-79.

40. David A. Sanchez-Hernandez, "*Multiband Integrated Antennas for 4G Terminals*", Artech House, United States of America, 2008, pp. 41-43.