Modelling of an electromagnetic wave radiation exposure on a smartphone by using the mat lab program

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Abstract. This research discussed the modelling of an electromagnetic wave radiation exposure on a smartphone which helped by the Mat Lab program. The modelling that was used to solve the intensity radiation was an inversion modelling. Inversion modelling can be defined as a mathematical and statistical method that used to obtain information based on observational data which is processed into formulation. The purpose of this research was to determine the strong forms of exposure that existed in smartphone with 3 G and 4 G network types. The difference of network types aimed to find out the different forms of the received exposure. The method that was used in this research was done by taking field data which was matched with the calculating data. In order to obtain the suitability of theoretical data and field data, an experimental process can be carried out so that the appropriate results will be obtained and illustrated in graphical form.

1. Introduction
For almost two decades, the concern on smartphones radiation which can affect human health has been widely discussed by the researchers. One of the founding organizations that set guidelines and standards based on specific peak absorption rates that limit exposure to electromagnetic fields is the Institute of Electrical and Electronics Engineers (IEEE) [1] and the International Commission of Non-Ionizing Radiation Protection (ICNIRP) [2]. When exposed to electromagnetic radiation, the radiated electromagnetic energy that is emitted will be absorbed by biological tissue in the body. The increased in tissue temperature is caused by the energy absorbed in the body being converted to heat. Every small rise in temperature due to this emission of energy affects the body’s tissues in the hypothalamus and eyes [3]. The temperature that rises in the hypothalamus reaches 0.2-0.3°C and in the eyes reaches 3-4°C which can form cataracts [4] and change the thermoregulatory behavior [5] respectively. However, in real situations, it is not possible to measure the temperature rise in the body directly. So that, modeling is needed that illustrated the actual, interaction process between electromagnetic radiation and human organs [6].

Smartphones for every level of society provide a convenient means of communication within the community [7]. Over the last two decades, choosing communication technology for personal needs caused electromagnetic pollution that was generated from a smartphone. The easiness of accessibility, usage, and low cost smartphone makes many people have their own smartphone due to their personal needs. In health care, in using a smartphone for communication with their relatives and friends, patients are more likely to put a smartphone beside their bed [8]. According to the literature, the
amount of peak power emitted from a smartphone is not only during the ring phase but in standby conditions [9]. This research reveals that one of the potential sources of interference with the work of many medical devices is caused by smartphones. The effects of smartphone radiation on human body tissues have been investigated. However, the investigation only discuss the maximum SAR value permitted by public safety standards and do not discussed the temperature distribution field in the network [10] and the radiation absorption capacity of smartphone with 3G and 4G networks. This results in the complete analysis results.

Previous studies discussing biological network have shown a rise in temperature and show the importance of considering SAR caused by electromagnetic radiation. Wessapan et al (2013) examined SAR with the effect of operating frequency and temperature increased, heterogeneously exposed to the electromagnetic field in human eye models [11]. Recently, Wessapan et al (2016) investigated the causes of EMF absorption near the field on increasing temperatures in the male reproductive system [12].

Exposure to the near field by electromagnetic absorption depends on the following factors, such as the frequency of smartphone operations, the distance between the smartphone and the human head and so on. In addition, there are many things that can be done by a new generation of smartphones. For example, if usually we only has voice call, now we can has video call with everyone, everytime and everywhere. The use of smartphones cause human heads and human eyes exposure by smartphone radiation. The effect will be different, it depends on the position of smartphone while using it [13]. Apart from the fact that the heads of smartphone users vary based on age and other parameters exposed, guidelines are made at the head base for adult sizes [14]. There are also many smartphone with low quality components at lower prices found in some smartphone models. Generally, the power supplied by normal phones 1-2 Watt. However, smartphone that has low quality can cause greater power emitted for some situations. Adverse effects on the human head are caused in some of these cases. Therefore, it is necessary to systematically describe the differences in 3G and 4G networks on smartphones with several conditions and positions and study the effects of various usage patterns on SAR that affect the blood and skin of the human body.

The first part of this article will analyze the magnetic field chart pattern for distances for several conditions. The second part is to find out the calculation of the value of frequency results per photon emitted by smartphones with the Mat Lab program. The third part is to find out which is the most ideal distance in used in terms of the SAR value generated in the form of graphs that are displayed. Maxwell’s equation is used to calculated electromagnetic wave propagation, as well as to measure frequency per photon based on the inversion process of electromagnetic wave energy using MatLab, and to measure SAR values based on the conductivity of tissue types in the body. In this article, only 2 conductivity reviews, namely on blood and skin and when used in different contexts, namely voice calls, video calls and browsing positions.

2. Method
This research was conducted in field, University of Jember in October 2019. This research consisted of several stages, including the preparation stage such as preparing tools and samples to be used in measurements, the stage of data collection in this research used the measuring instrument EMF-Tester 827 to measured magnetic field with a measurement distance of 2 cm to 30 cm with an interval of 2 cm, measurements were made during the conditions of voice call, video call and browsing, the analysis stage in making modeling in inversion by entering data from the field then carried out the calculation process with Mat Lab, the results of data already obtained in the form of graphs, then conclusions.

The data analysis stage uses Maxwell’s equations, where there are 4 Maxwell’s equations for electromagnetic wave in the electrostatic and magnetic fields, namely:

\[ \nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0} \]  
\[ \nabla \times \vec{E} = \vec{0} \]  
\[ \nabla \cdot \vec{B} = 0 \]  
\[ \nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t} \]  

(1)

(2)
\[ \nabla \times \vec{B} = 0 \]  
(3)

\[ \nabla \times \vec{B} = \mu_0 \vec{j} \]  
(4)

States that the source of an electromagnetic field in the form of an electric charge and is monopolistic means that just one pole can produce an electric field. States that electrostatics does not recognize a current source (circulation) and is conservative. States that the magnetic field does not recognize a monopoly source (magnetic charge) meaning that in practice there are always two magnetic poles (dipoles) namely the north pole and the south pole. And states the source of the magnetostatic field in the form of an electric current.

The formulation of the electromagnetic field energy shows that:

Electromagnetic waves are one type of interference that does not require intermediate propagation medium. This work or energy is a combination of magnetic field energy and electric field. In general, the formulation of electromagnetic field energy is,

\[ W_{el} = \frac{\varepsilon_0}{2} \int E^2 \, dV \]  
(5)

\[ W_{mag} = \frac{1}{2}\mu_0 \int B^2 \, dV \]  
(6)

Where \( E \) is the resultant electric field and \( B \) is the resultant magnetic field. The total energy stored in the electromagnetic filed is as followed,

\[ W_{EM} = \frac{1}{2} \left( \varepsilon_0 E^2 + \frac{1}{\mu_0} B^2 \right) dV \]  
(7)

Electromagnetic field that propagate in a vacuum have that relation \( E = cB \) and \( c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \) so that :

\[ W_{EM} = \frac{1}{\mu_0} \int B^2 \, dV \]  
(8)

Radiation field are emitted in all directions, so the volume limit used is spherical.

\[ W_{EM} = \frac{4B^2\pi r^3}{3\mu_0} \]  
(9)

The energy of the emitted electromagnetic field is proportional to the magnitude of the frequency of the electromagnetic wave, \( W_{EM} = E_n = nhf \). In this case \( n \) is the number of photons colliding and \( h \) is a planck constant.

\[ nhf = \frac{4B^2\pi r^3}{3\mu_0} \]  
(10)

\[ \frac{3\mu_0 h}{4\pi r^3} f = \frac{B^2}{n} \]  
(11)

Here we will look for frequency values for each measurement using numerical inversion methods. Here we define it \( A = \frac{3\mu_0 h}{4\pi r^3} \), where \( A \) is a kernel matrix with a matrix size \((n \times 1)\). As for the data \( b = B^2 \) with a matrix size \((n \times 1)\). Later we will get an electromagnetic wave frequency value per photon.

\[ Af = b \]  
(12)

Gauss elimination method is a method uses in the process of solving numerical calculation in matlab program. Elimination method is a method that is often used to get an exact value.

Measurements of electromagnetic energy that can be absorbed by body tissues against smartphone use are expressed in units of Watts per kilogram (W/Kg) [15]

The SAR formula is stated in :

\[ SAR = \frac{\sigma |C.B|^2}{\rho} \]  
(13)

Density of tissue(\( \rho \)) is 1000 kg/m\(^3\). As for the value of \( \sigma \) which is called conductivity depends on the type of tissue that is in the human body. In this study conductivity value of the skin is 0.42 S/m and the blood is 1.22 S/m [16].
3. Result and Discussion

Smartphone is a must in today’s era. Almost everyone already has this item. As a result, the number of smartphone users increases dramatically every year. The duration of smartphone usage is also increasing along with current technological developments. This has caused some scientists to pay great attention to this phenomenon. The risk of being affected by radiation from smartphones is also something that is often discussed by academics today. Researches on the effects of smartphone radiation or electronic goods have been carried out either directly on mouse objects or on humans. Most electronic devices including smartphones emit radiofrequency field of 3 kHz – 300 GHz.

In this study the researchers wanted to show the large differences in the magnetic field radiation with a certain distance range shown in Figure 1 below:

![Graph of the magnetic field with respect to distance for each condition](image)

**Figure 1.** Differences in magnetic field radiation in measurements with a range of 2 cm – 30 cm for each condition, namely voice calls, video calls, and browsing with 3 G and 4 G networks.

The result showed that there were significant differences between the measured magnetic fields when using 3 G and 4 G network types. The magnetic field when using a 4 G type network is higher because the frequency used on this network is also higher that the 3 G network. This research measures the magnitude of the magnetic field in a certain distance range from a smartphone. To find the frequency emitted by electromagnetic waves we use the inversion method. In the existing literature found for 3 G network to have a frequency 1.900 MHz and for 4 G network it has a frequency 2100 MHz [17]. This is due to the influence of external magnetic fields during the measurement process.

The magnitude of the frequency of electromagnetic waves possessed by smartphone is shown in Table 1 as follows:

| No. | Condition of Smartphone | Frequency/photon (Hz/photon) |
|-----|-------------------------|------------------------------|
| 1   | 3 G voice call           | $3,9724 \times 10^{20}$      |
| 2   | 4 G voice call           | $5,6802 \times 10^{21}$      |
| 3   | 3 G video call           | $4,5474 \times 10^{20}$      |
| 4   | 4 G video call           | $5,2949 \times 10^{21}$      |
| 5   | Browsing 3G              | $6,0098 \times 10^{20}$      |
| No. | Condition of Smartphone | Frequency/photon (Hz/photon) |
|-----|------------------------|-----------------------------|
| 6   | Browsing 4G            | $5,3393 \times 10^{21}$     |

Table 1 above shows using the assumption that the number of photons emanating from smartphone is the same, so we can see that in 4 G network conditions have a frequency that is about 10 times stronger that 3 G network. This means that the photons that will hit our bodies have more energy in the condition of the 4 G network. Although this radiation is a type of non-ionizing radiation which in fact is not dangerous but if it is used is done at intervals of time will cause health effects as well.

Measurement of electromagnetic energy that can be absorbed by body tissues against smartphone use are expressed in units of Watts per kilogram (W/Kg). The threshold set by ICNIRP is 2.0 W/Kg. Whereas The Institute of Electrical Engineers (IEEE) sets a threshold of 1.6 W/Kg [18]. The SAR value absorbed due to the emission of electromagnetic wave radiation is shown by the following Figure 2:

![Figure 2](image)

**Figure 2.** SAR value absorbed by (a) blood and (b) skin due to radiation from electromagnetic waves.

From the calculation of the SAR value shown in Figure 2, it is clear that in 3 G networks it still tends to be safer because the maximum SAR value is only at 0.5 W/Kg and tends to decrease in value when the distance of the smartphone is getting farther away. Whereas the used of a 4 G network has a very high SAR value, even exceeding a predetermined threshold. The skin is the first member of
body tissue to absorb this electromagnetic wave radiation. So that the use of smartphone becomes safer if used at a distance of more than 15 cm from our body. Human blood has a higher electrical conductivity when compared to human skin, but the radiation form this smartphone will not all be absorbed by human blood, because it has previously been absorbed or retained by the skin.

A number of studies in the world have proven that electromagnetic waves emitted by smartphones have influenced on the human body. The effects include changes in microscopic and functional structures including biochemical changes. Several studies have shown that electromagnetic waves can interfered with the regulation of glucose metabolism in the body. The mechanism that caused this is the stress mechanism. Stressors from electromagnetic waves activate the hypothalamus-pituitary-adrenal (HPA) axis, which causes the hypothalamus to secrete corticotropin-releasing hormone (CRH) and arginine vasopressin (AVP). The CRH hormone will stimulate anterior hypotension to secrete adrenocorticotropic hormone (ACTH). Then ACTH will stimulate the adrenal cortex to secrete cortisol. Cortisol wool spur increased gluconeogenesis and insulin resistance. Furthermore, gluconeogenesis and insulin resistance will result in an increase in blood glucose levels [19].

Besides, the effects caused by electromagnetic wave radiation by smartphones that affect the physiological effects and psychological effects. Physiological effects result in disorders of the organs of the human body such as brain and hearing cancers, tumors, changes in eye tissue, disorders in reproduction, headaches and others. The psychological effects caused by repeat radiation is resulting in the stress and discomfort [20].

The used of smartphones can increased blood glucose levels in the body. The longer the duration of used of the smartphone will affect the balance of blood glucose levels in the body. High blood sugar levels are also referred to as hyperglycemia which is usually characterized by increased thirst or hunger, frequent urination, headaches, blurred vision, nausea and vomiting. Futhermore, if blood sugar levels are too high, it can cause diabetic complications such as diabetic ketoacidosis and hyperglycemic hyperosmolar. This is due to the effect of radiation exposure which, although in non-ionizing radiation, if the longer exposed will affect health.

4. Conclusion
This article investigate the graphic pattern of magnetic fields with respect to distance on smartphones for several conditions. The difference between the measurement data obtained by the inversion data from the MatLab calculation results in a significant difference between 3G and 4G networks. This is due to the frequency owned by 3G and 4G networks. This study also includes knowing the calculation of the value of frequency results per photon emitted by smartphones with the Mat Lab program. The results showed that in voice calls with a 4G network the highest frequency per photon value is 5.6802 x 1021. This study also includes knowledge on which distance is most ideal for use in terms of the SAR value generated in the form of graphs displayed. The results show that in the case of 3G networks it still tends to be safer in body tissues in the blood and also in the skin tissue because it is in the SAR range while in the 4G network it is found to exceed the exposure limit set by SAR both in the body tissue in the blood and body tissue in the skin.

Based on review and research results can be given advice when using a smartphone can be wise in it is use and within a relatively safe range of body tissue and with the duration of use is not too long. Smartphones usage when using a 4G network of electromagnetic wave radiation shows very large results and is quite influential compare to using a 3G network. Further research must continue to be done in order to find out the magnitude of electromagnetic wave radiation on smartphone when the 5G network and it is better in further research to find the type of material that is able to dispel the radiation emitted by the smartphone so that it is use be safer.

References
[1] ICNIRP Guidlines.1998. Guidlines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHZ). Health Phys. 74:494-522.
[2] IEEE Study. 2006. IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz. *IEEE Std C95.1-2005 (Revision of IEEE Std C95.1-1991)*. 1-238.

[3] D. Bhargava, N. Leeprechanon. 2017. A review of the effect of non-ionizing microwave radiation on human health science and technology asia. 22: 65-82.

[4] A Hirata, M. Morita, T. Shiozawa. 2003. Temperature increase in the human head due to a dipole antenna at microwave frequencies. *IEEE Trans, Electromagnetic, Compat.* 45: 109-116.

[5] C. Bucella, V. D. Santis, M. Feliziani. 2007. Prediction of temperature increase in human eyes due to RF souces. *IEEE Trans, Electromagnetic, Compat.* 49:825-833.

[6] A. Joukar, E. Nammakie, H. Niroomand-Oscuii. 2015. A comparative study of thermal effect of 3 types of laser in eye: 3D simulation with biohet equation. *J. Therm. Biol.* 49-50: 74-81.

[7] Sorri MJ. Piiparinen PJ, Huttunen KH, Habo MJ. 2006. Solution to electromagnetic interference problems between cochlear implant and GSM phones. *IEEE Trans Neural Syst Rehabil Eng.* 14(1):101-109.

[8] Klein, AA. Djaiani, GN. 2003. Mobile phones in the hospital –past, present and future. *Anaesthesia.* 58(4): 353-340.

[9] Lawrentschuk N, Bolton DM. 2004. Mobile phone interference with medical equipment and its clinal relevance: a systematic review. *Med J Aust.* 181(3): 145-149.

[10] M.I Hossain, M.R.R. Faruque, M.T. Islam. 2015. Analysis on the effect of the distances and inclination angles between human head and mobile phone on SAR. *Progr.Biophys. Mol. Biol.* 119:103-110.

[11] T. Wessapan, P. Rattanadecho. 2013. Specific absorption rate and temperature increase in the human eye due to electromagnetic fields exposure at differate frequencies, Int. J. Heat Mass Transf. 64:426-435.

[12] T. Wessapan, P. Rattanadecho. 2016. Temperature induced in the testicular and related tissues due to electromagnetic fields exposure at 900 MHz and 1800 MHz, Int. J. Heat Mass Transf. 102:1130-1140.

[13] A. Hadjem, E. Conil, A. Gatti, M. F. Wong, j. Wiart. 2010. Analysis of power absorbed by children’s head as a result of new usages of mobile phone. *IEEE Trans. Electromgn. Compat.* 52:812-819.

[14] O. P. Gandhi, L.L. Morgan, A.A. de Salles, Y. Y. Han, R. B. Herberman, D.L. Davis. 2012. Exposure Limits: the underestimation of absorbed cell phone radiation especially in children. *Electromagn. Bio. Med.* 31:34-51.

[15] Sallomi, Adheed Hasan. 2012. A theoretical approach for SAR calculation in human head exposed to RF signals. *Journal of engineering and development.* 16(4): 304-313.

[16] Sullivan, Dennis. M. D. T. Borup, and O. P. Gandhi. 1987. Use of the finite-difference time-domain method in calculating EM absorption in human tissues. *IEEE Transactions on Biomedical Engineering.* 34(2): 148-157.

[17] Ramya, C., S., R., P., Sheba, K., A., S. J., dan Manivannan, P. 2018. Mobile Phone detector using OP-AMP. 7(1):231-235.

[18] Bhargava, Deepshika,. N. Leeprechanon., P. Rattanadecho., and T. Wessapan. 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.

[19] Dewi, I. K., and Wulan, A. J. 2015. Efek paparan gelombang elektromagnetik handphone terhadap kadar glukosa darah. *Majority.* 4:31-37.

[20] Swamardika, Alit. 2010. Pengaruh radiasi gelombang elektromagnetik terhadap kesehatan manusia. *Journal Teknologi Elektro.* 8(1): 106-109.