JOURNAL OF ENGINEERING, EMERGING TECHNOLOGIES AND APPLIED SCIENCES (JEETAS)

A PUBLICATION OF THE FACULTY OF ENGINEERING, NIGER DELTA UNIVERSITY

NOVEMBER 2023 VOLUME 01 ISSUE 02 ISSN: 1116 - 4514

ARTICLES

NIGER DELTA UNIVERSITY

Journal of Engineering, Emerging Technologies and Applied Sciences -– Volume 1 Issue 2, Nov. 2023

Available at ***https://www.ndu.edu.ng/journalofengineering/***

RESEARCH ARTICLE OPEN ACCESS

Analysis of Electromagnetic Wave Propagation in Human Tissue

Godday Biowei*, Sulaiman A. Adekola**, Ayibapreye K. Benjamin*

*Electrical and Electronic Engineering, Niger Delta University, Nigeria

Email: biogod@ndu.edu.ng

**Department of Electrical and Electronic Engineering, Federal University Otuoke, Nigeria

--************************----------------------------------

Abstract:

This paper reports the analysis of EM wave propagation in human tissue, with specific reference to radio-frequency wave propagation. Maxwell's equation is applied to analyse and model the behaviour of the EM wave as it transits from the free-space as a source-free region into human tissue. Maxwell's equations have never been used in this manner before. The transmitted wave is theoretically followed into the human skin. Measured electric fields from GSM towers and frequencies used by the four major wireless service providers in Nigeria, coupled with the modelled equation for the transmitted wave in the skin are used to simulate the wave propagation in the tissue. MATLAB software, a versatile engineering tool is used to simulate the propagation model in human tissue. Measurement of the EM wave radiated by some sources into free-space is carried out. Results obtained from computation using the developed propagation model in human tissue are compared with standards and existing results. Results show that the EM wave radiating around our immediate environment and hitting our skin does not travel deep into our body. The frequencies used by these GSM network providers for 3G and 4G transmission are low and do not possess enough energy to cause damage to the tissue.

Keywords — **Analysis, Electromagnetic, Wave Propagation, Human Tissue**

--************************----------------------------------

I. INTRODUCTION

One of the world's fastest-growing technologies, mobile phone technology, has become a popular and essential part of our daily lives. Significant improvements in internet data transmission speed and quality have been achieved as a result of technological advancement, as have modern communications such as Wi-Fi, UMTS (Universal Mobile Telecommunications System), EDGE (Enhanced Data Rates for GSM Evolution), WiMAX (Worldwide Interoperability for Microwave Access), and 4G have been developed. It is now a common sight to see wireless base stations (BS) in residential areas radiating radio frequency (RF) waves.

RF wave is part of the electromagnetic (EM) wave spectrum which is produced by a variety of electrical systems, including mobile phones, microwave ovens, communication base stations, high-voltage power lines, electronic instruments and electromagnetic equipment. EM devices generate a variety of electromagnetic waves of varying frequencies, resulting in an increase in EM radiation in human living areas. This has led to increased health concerns about the RF-EM radiation emission from GSM towers by the general public who consider this as environmental pollution. The EM wave spectrum is divided into two parts, the non-ionizing and ionizing radiation. RF wave used for wireless communications belong to the non-ionizing radiation, which radiates with frequencies that have low photon energy. Photon energy of this magnitude is incapable of causing any permanent damage to the human tissue. The energy is too low any form of ionization, that is break chemical bonds.

(Gabriel et al, 1986) studied the effect of various frequencies on the permittivity (ε) and conductivity (σ) of the human tissue and results showed that the permittivity decreases and the conductivity increases when the frequency of a wave hitting the skin increases.

The four major GSM providers in Nigeria, which are Glo Ng., MTN Ng., Airtel Ng., and 9Mobile, use the same frequency band 1(2100MHz), which has bandwidth of between (2110-2170) MHz for 3G network transmissions. For 4G network transmissions, Glo Ng. uses the band 28(700MHz), which has a bandwidth of between (758-803) MHz and band 3(1800MHz) having a bandwidth of between (1805-1880) MHz. MTN Ng., uses band 7(2600MHz) having a bandwidth of between (2620-2690) MHz, band 20(800MHz) having a bandwidth of between (721-821) MHz and band 42(3500MHz) having a bandwidth of between (3400-3600) MHz for the 4G network transmissions. Airtel NG. and 9Mobile NG. both use band B3(1800MHz) for 4G network transmissions. The lower or higher frequencies of these frequency bands may be use to simulate the EM propagation in human tissue.

II. BACKGROUND THEORY

The electrical characteristics of the tissue must be understood in order to investigate how EM field radiation affects biological tissue (A. Lewandovski, A. Szyplowska, M. Kafarski A. Wilczek, P. Barmuta and W. Skierucha, 2017) (W. Skierucha and A. Wilczek, 2010). The biological effects that are created when biological tissue is exposed to EM wave radiation rely on the electrical characteristics of the tissue (Alabaster, 2003). Relative permittivity (ε_r) , conductivity (σ) and charge density (ρ) are three electrical properties that are typically used to describe electrical materials. Most living organisms are made up of huge number of cells of varying electromagnetic properties (J. Chung and J. Shim, 2020) (J. Behari, Z. H. Zaidi and Z. C. Alex, 1994). The most important aspect of studying the biological effects of EM field radiation on biological tissues is the characteristics they possess when subjected radiation from EM wave of different frequencies.

The electrical properties of every material medium distinctly divide them into two categories: conductors and insulators (dielectrics) (R. Ramirez-Vazquez, E. Arribas. Thielens and I. Escober, A., 2020). When an electric field is applied, materials with conductive properties have charges that can move about freely (M. D. Devine and R. G. Vaughan , 2007). While in the case of insulators (dielectrics), charges are fixed, never free to move, when an electric field is applied. In some materials, however, their molecules have negative and positive charges that do not line up. As a result, the material develops an electric dipole moment. By positioning the dipoles, an applied field produces an opposite field in the dielectric. The majority of materials are distinguished by having a mixture of free charges and orientable dipoles, which reduces the induced electric field relative to applied electric field in free space (H. Nikawa, H. Yamashiro, T. Hamada, H. Kumagai,, 1999). An induced electric field in an insulator is substantially smaller than the electric field applied, whereas in the instance of a good conductor, it is practically non-existent. The relative permittivity ε of these materials is what causes their induced electric field to be reduced.

The human tissue possesses characteristics of both an insulator and a conductor. This is because it possesses charges with restricted movement as well as dipoles. The heterogeneous nature of the human tissue may cause charges to be trapped at an interface. Whenever an electric field is applied to human tissue, negative and positive ions tend to travel in opposite directions. This causes a charge separation that behaves like a large dipole because internal polarization is produced. Thus, the human tissue may be described as a material having relative permittivity ε_r and conductivity σ . Electrical permittivity of a material characterizes its ability to store charge particles and/ or rotate molecular dipole while its ability to transport charge particles is conductivity.

The relative permittivity governs how fast a wave propagates in human tissue. For a homogeneous medium such as free-space, the relative permittivity is unity, giving the value of permittivity as $\varepsilon_0\,(8.85 \times 10^{-12} F/m)$. Whilst conduction current doesn't change at all in free space the displacement current does increase with frequency due to the constant electrical characteristics (ε_r and σ). Homogeneous medium like free-space behaves like a conductor to a low frequency EM field but appears capacitive at high frequencies. Inhomogeneous or non-homogenous material like the human tissue, however, does not have constant electrical properties. An inhomogeneous material's electrical properties depend on the frequency of the induced EM field (M. Ziane, R. Sauleau, and M. Zhadobov.). This dependency of electrical properties of the human tissue on frequency of propagating field makes it dispersive (B. Julian, D. Andrea, F. Iman, F. Lourdes, C. V. Sammut, 2020). Therefore, conductivity σ^* and permittivity ε^* are dependent on the applied electric field's frequency and this dependency is referred to as dispersion. The human tissue displays several different dispersions over a wide frequency range (D. Yinliang, E. A. Rashed and A. Hirata., 2020). Thus, dispersion phenomenon characterizes the movement of charge carriers and dipole orientation in an inhomogeneous material.

A. Modelling of Transmitted Wave Propagation in the Human Tissue

This section concerns itself with the transmitted EM wave into the human tissue. It is therefore, imperative to investigate the properties of the human tissue in order to ascertain how the transmitted EM wave behaves inside the human tissue. It is now appropriate to consider the dynamic internal structure of Maxwell's equations in the human tissue. Having established that fields transmitted (E-and H-fields) into the human tissue are merely component parts of the EM wave that is incident on the skin from the empty-space, it is necessary to investigate how those fields propagate in the human tissue. For one thing, it is instructive to realize that the human tissue has a non-zero coefficient of conduction $(\sigma \neq 0)$, although the net charge density denoted by ρ is zero as earlier pointed out in section 3.1.1. With this in mind, one can see at once that the situation of EM wave propagation in the human tissue.

B Dynamic Internal Structure of Maxwell's equations inside the Human Tissue

If the charge and current densities are non-existent, the right-hand sides of all four Maxwell's equations become zeros as described by (6) – (9), which led to oscillating wave defined by (20). Once the oscillating wave is incident on the skin, the transmitted or refracted wave enters the human tissue. Since conductivity (σ) exists inside the human tissue, the transmitted electric field $(\mathbf{E}_t)$ component of the incident EM wave engages the conductivity and couples with it. As far as the charge density ρ is concerned, the human flesh is charge-neutral. Based on the foregoing discussion, Maxwell's equations in the human tissue assume forms characterized by,

$$\nabla \cdot \mathbf{E}_t = 0 \tag{1}$$

$$\nabla \times \mathbf{B}_t - \mu\varepsilon \frac{\partial \mathbf{D}_t}{\partial t} = \mu \mathbf{J} \tag{2}$$

$$\nabla \cdot \mathbf{B}_t = 0 \tag{3}$$

$$\nabla \times \mathbf{E}_t + \frac{\partial \mathbf{B}_t}{\partial t} = 0 \tag{4}$$

provided

$$\mathbf{J}_t = \sigma \mathbf{E}_t \tag{5}$$

where the subscript 't' stands for transmitted quantities for example, $\mathbf{E}_t$ is the electric field transmitted across the boundary.

From wave propagation viewpoint, propagation in a lossy medium is characterized by two parameters, the propagation constant β (which propels and drives the wave) and the attenuation constant α (which acts as damper). These two parameters need to be determined for human tissue in order to accurately describe the behaviour of the transmitted wave in the human skin. This is realized as follows.

Let us re-write (2), (4) – (5) in terms of appropriate constitutive relations as

$$\nabla \times \mathbf{H}_t = \sigma \mathbf{E}_t + j\omega\varepsilon \mathbf{E}_t \tag{6}$$

$$\nabla \times \mathbf{E}_t = -j\omega\mu \mathbf{H}_t \tag{7}$$

$$\mathbf{J}_t = \sigma \mathbf{E}_t \tag{8}$$

where $e^{j\omega t}$ time variation is assumed in arriving at (6) and (7). Taking the curls of (6) and (7), one obtains

$$\nabla \times \nabla \times \mathbf{H}_t = \sigma \nabla \times \mathbf{E}_t + j\omega\varepsilon \nabla \times \mathbf{E}_t \tag{9}$$

and,

$$\nabla \times \nabla \times \mathbf{E}_t = -j\omega\mu \nabla \times \mathbf{H}_t \tag{10}$$

respectively. In Cartesian coordinates, the Laplacian of a vector $\mathbf{A}$ assumes a form given as

$$\nabla^2 \mathbf{A} = \mathbf{x}\nabla^2 A_x + \mathbf{y}\nabla^2 A_y + \mathbf{z}\nabla^2 A_z \tag{11}$$

Using the vector theorem stated in (11) concerning the curl of the curl of an arbitrary vector in (9) and (10), one arrives at the vector wave equation for the electric field as

$$\nabla^2 \mathbf{E}_t = j\omega\mu(\sigma + j\omega\varepsilon)\mathbf{E}_t = \gamma^2 \mathbf{E}_t \tag{12}$$

and the magnetic field as

$$\nabla^2 \mathbf{H}_t = j\omega\mu(\sigma + j\omega\varepsilon)\mathbf{H}_t = \gamma^2 \mathbf{H}_t \tag{13}$$

provided

$$\gamma^2 = j\omega\mu(\sigma + j\omega\varepsilon) = (j\omega)^2 \mu\left(\varepsilon + \frac{\sigma}{j\omega}\right) \tag{14}$$

is defined as the complex propagation constant, from which, one obtains

$$\gamma = j\omega\sqrt{\mu\left(\varepsilon + \frac{\sigma}{j\omega}\right)} \tag{15}$$

In terms of its real and imaginary part, γ is given as

$$\gamma = \alpha + j\beta \tag{16}$$

Equating (15) and (16) leads to

$$\alpha + j\beta = j\omega\sqrt{\mu\left(\varepsilon + \frac{\sigma}{j\omega}\right)}$$

which upon mathematical manipulations yield

$$\alpha^2 - \beta^2 + j2\alpha\beta = -\omega^2\mu\varepsilon + j\omega\mu\sigma \tag{17}$$

Equating real and imaginary parts on both sides of (17), one arrives at

$$\alpha^2 - \beta^2 = -\omega^2\mu\varepsilon \tag{18}$$

$$2\alpha\beta = \omega\mu\sigma$$

(19)

Equations (18) and (19) constitute two non-linear equations that are solved simultaneously for α and β to yield

$$\alpha = \frac{\omega\sqrt{\mu\varepsilon}}{2}\sqrt{\left[1 + \left(\frac{\sigma}{\omega\varepsilon}\right)^2 - 1\right]} \text{ Np/m} \tag{20}$$

as the attenuation constant while the propagation constant is determined to be

$$\beta = \frac{\omega\sqrt{\mu\varepsilon}}{2}\sqrt{\left[1 + \left(\frac{\sigma}{\omega\varepsilon}\right)^2 + 1\right]} \text{ rad/m} \tag{21}$$

Equations (20) and (21) define the attenuation and propagation constant, respectively, in terms of the conductivity, when human tissue is assumed to be lossy medium.

However, when the human tissue is considered to be conductive, meaning that the value of the loss tangent $(\sigma/\omega\varepsilon)$ in each of (20) and (21) is far greater than unity $(\sigma/\omega\varepsilon >> 1)$. Under this condition, expressions given in (20) and (21) for α and β are approximated as

$$\beta \approx \omega\sqrt{\frac{\mu\varepsilon}{2}\left(\frac{\sigma}{\omega\varepsilon} + 1\right)} = \omega\sqrt{\frac{\mu\varepsilon}{2}\left(\frac{\sigma}{\omega\varepsilon}\right)} = \omega\sqrt{\frac{\mu\sigma}{2\omega}} = \sqrt{\frac{\omega^2\mu\sigma}{2\omega}} = \sqrt{\frac{\omega\mu\sigma}{2}} \tag{22}$$

$$\alpha \approx \omega\sqrt{\frac{\mu\varepsilon}{2}\left(\frac{\sigma}{\omega\varepsilon} + 1\right)} = \omega\sqrt{\frac{\mu\varepsilon}{2}\left(\frac{\sigma}{\omega\varepsilon}\right)} = \omega\sqrt{\frac{\mu\sigma}{2\omega}} = \sqrt{\frac{\omega^2\mu\sigma}{2\omega}} = \sqrt{\frac{\omega\mu\sigma}{2}} \tag{23}$$

Therefore,

$$\alpha = \beta = \sqrt{\frac{\omega\mu\sigma}{2}} = \sqrt{\frac{2\pi f \mu\sigma}{2}} = \sqrt{\pi f \mu\sigma} \qquad (24)$$

Using the results obtained for attenuation and propagation constant along with that of the transmitted wave at the free space-skin boundary, the propagating wave in the human skin assumes this form

$$E_i(z,t) = E_0 e^{-\alpha z} e^{j(\omega t - \beta z)} = Re\{E_0 e^{-\alpha z} e^{j(\omega t - \beta z)}\}$$

$$E_i(z,t) = E_0 e^{-\alpha z} Cos(\omega t - \beta z) \qquad (25)$$

The transmitted electric field into the human skin is given as the form

$$\mathbf{E}_t(z,t) = \tau \mathrm{E}_0 e^{-\alpha z} \cos(\omega t - \beta z) \qquad (26)$$

where, τ is the transmission coefficient of the wave propagating into the medium.
where α and β are defined by (20) and (21) when human tissue is considered lossy and by (24) if the tissue is treated as a good conducting medium.

III. THE HUMAN SKIN AND ITS PROPERTIES

To determine the actual position of the tran smitted wave when it completely attenuates to zero in the human body, it is important to know the skin properties and its dimensions. This is due to the fact that the wave penetration into the human body does not go beyond the skin.

A. Electrical Properties of the Human Skin

The behaviour of a wave in a medium is determine by the electrical properties. For an inhomogeneous medium like the human tissue, wave penetration is affected by attenuation due to the presence of conductivity (σ). The human skin which is the first line of defense against external elements have three distinct electrical properties; namely: relative permittivity (ε_r), permeability (μ), and conductivity (σ), that determines if

B. Structure of the Human Skin

The skin is the largest organ of the human body, covering the whole exterior and protecting the body's internal organs from external elements. The structure of the skin is illustrated in Fig.1. This shows the three major layers of the human skin; namely: Epidermis, Dermis and Subcutaneous Fat. The epidermis is the top layer, it has a thickness band depending on the location of the body of between (0.06 – 0.1) mm. This followed by the dermis which has a thickness band of between (1.2 – 2.8) mm and finally the subcutaneous fat layer with a thickness band of between (1.1 – 5.6) mm.

The diagram of the skin here presented is used to illustrate the point with which the propagating wave will completely attenuate to zero. Thus, comparing the dimensions of the skin to the distance travelled by the EM wave when it penetrates the skin, will give a clear indication of layer of the skin the wave will completely stop travelling.

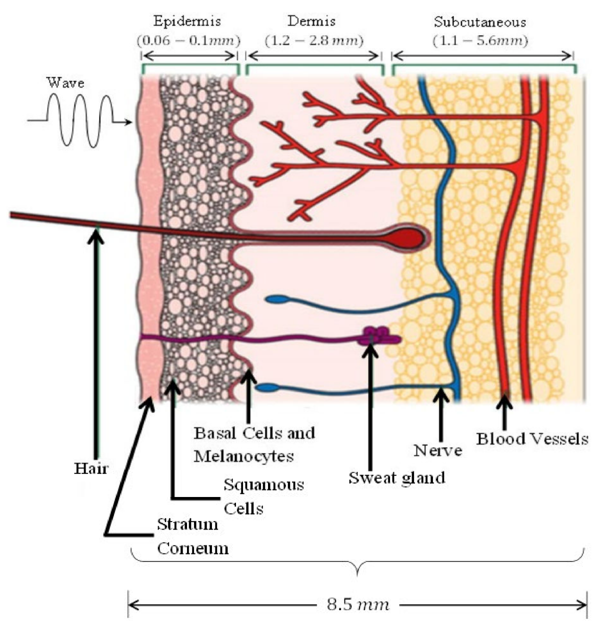

Fig. 1 Structure of the human skin

IV. RESULTS AND DISCUSSION

A. Measured Data

The field meter is pointed in the direction of the telecommunication tower, towards the source antenna. The device measures the electric field emitted by the antenna and also obtains the magnetic field and power density. It does not capture the frequency with which the signal is transmitted.

Fig. 2 Electrosmog Meter

In Fig. 2 is the Electrosmog meter used to carry out field measurements.

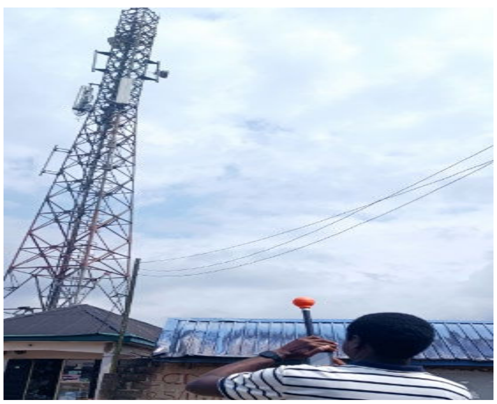

Fig. 3 Use of field meter

Fig. 3 shows a demonstration of the devices being used for the measurements carried out in this work. The meter is held out with the probe pointing in the direction of the communication tower holding the transmitting antenna. The meter receives the EM signal just like a GSM phone does and process the data, it then provides values for the electric and magnetic fields.

values for the electric fields used for simulations of the RF wave propagating into the human skin. The maximum values for network provider were used in the simulations. 7.759 V/m was used for MTN, 4.096 V/m was used for Glo, 10.68 V/m was used for Airtel and 6.847 V/m was used for 9Mobile. The time limit for each measurement was sixty seconds (60s).

B. Wave Penetration Depth in the Human Skin

Figs. 2 to 5 are the curve patterns of the EM wave propagating in the human skin. This is done for the four major network providers in Nigeria; namely: MTN, Glo, Airtel and 9Mobile. These were carried out for the frequency band between 2110MHz to 2170MHz used for downlink wireless telephony by all the network providers for 3G transmissions. In Fig.4 (a) the penetration depth of the MTN RF wave radiating into human skin is approximately 0.103 mm at a frequency 2110MHz. This is approximately 100% penetration into the epidermis of the skin and this is the same for Fig.5 (a) for Glo, Fig.4 (a) for Airtel and Fig.5 (a) for 9Mobile. Fig.1 (b) at a frequency of 2170MHz the penetration depth of MTN is approximately 0.099 mm, which is about 99% penetration into the epidermis of a maximum thickness 0.1 mm as seen in Fig.1. There is a slight difference in the penetration depths between the wave at 2110NHz and 2170MHz. This is not much due to the fact that both frequencies are close.

When the frequency of the propagating wave is increased to 30GHz, one can see a marked difference in the penetration depth into the skin. The penetration depth is vastly reduced in this case as seen in Fig.6. The increased frequency has caused a reduction of the wave penetration to a value very close to the surface of the skin as compared with curves of Figs. 2 to Fig.5. What is also observed here is that the magnitude of the electric field ($\boldsymbol{E}$) does not alter the penetration as can be seen in Fig.6. In Fig.6 (a) the electric field value used is 7.759 V/m while in (b) the value used is 20 V/m and both curves the penetration depth is clearly seen to be the same. This is an indication that the frequency alone determines the depth at which a particular wave attenuates to zero in human tissue.

When the frequency of the propagating wave is increased to 30GHz, one can see a marked difference in the penetration depth into the skin. The penetration depth is vastly reduced in this case as seen in Fig.6. The increased frequency has caused a reduction of the wave penetration to a value very close to the surface of the skin as

compared with curves of Figs. 2 to Fig.5. What is also observed here is that the magnitude of the electric field $(\boldsymbol{E})$ does not alter the penetration as can be seen in Fig.6. In Fig.6 (a) the electric field value used is 7.759 V/m while in (b) the value used is 20 V/m and both curves the penetration depth is clearly seen to be the same. This is an indication that the frequency alone determines the depth at which a particular wave attenuates to zero in human tissue.

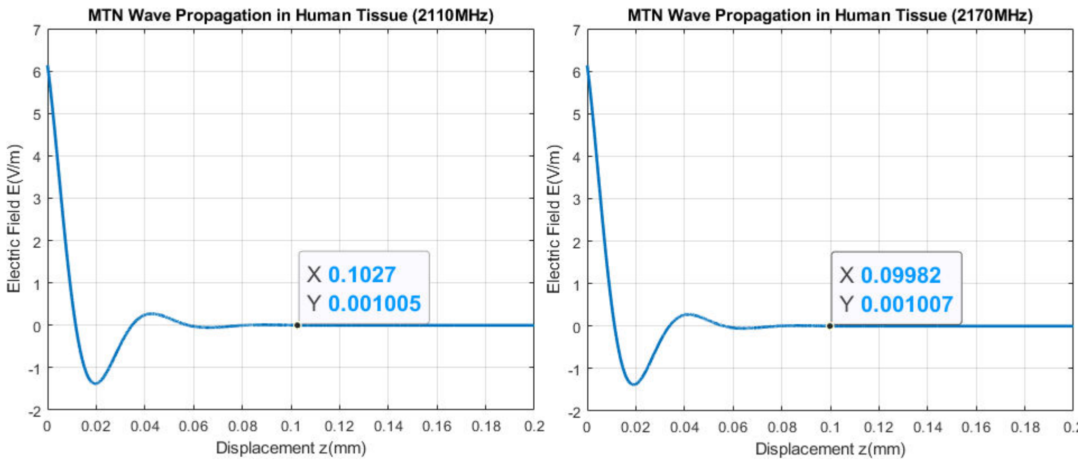

Fig. 4 Wave propagation in human tissue from MTN tower (a) 2110MHz (b) 2170MHz

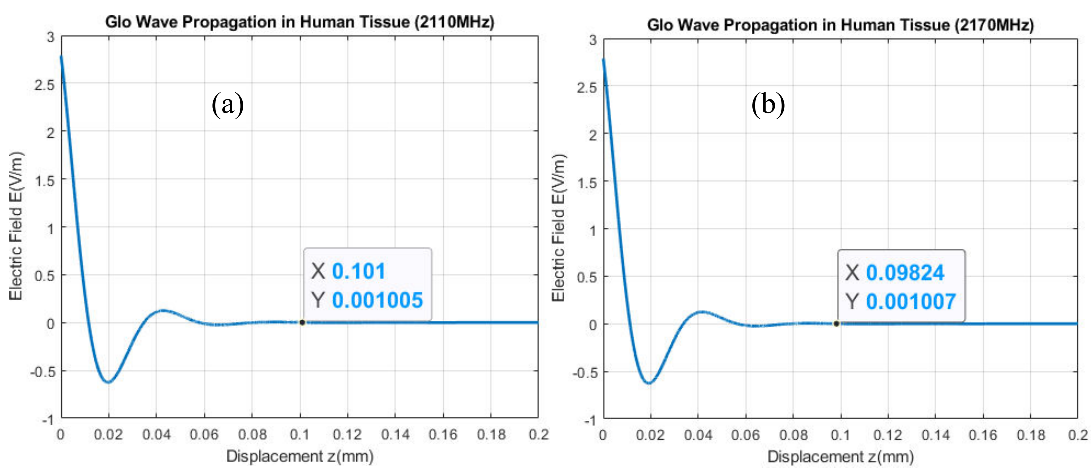

Fig. 5 Wave propagation in human tissue from Glo tower (a) 2110MHz (b) 2170MHz

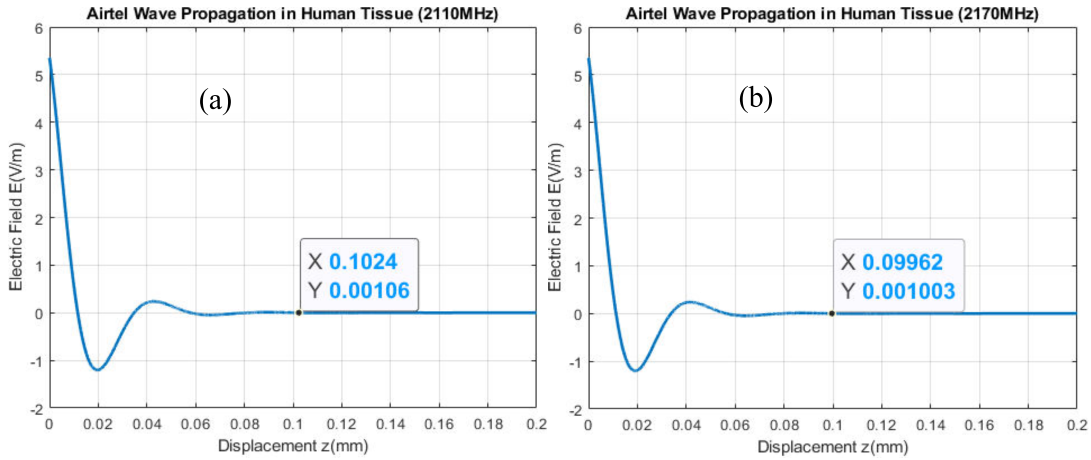

Fig. 6 Wave propagation in human tissue from Airtel tower (a) 2110MHz (b) 2170MHz

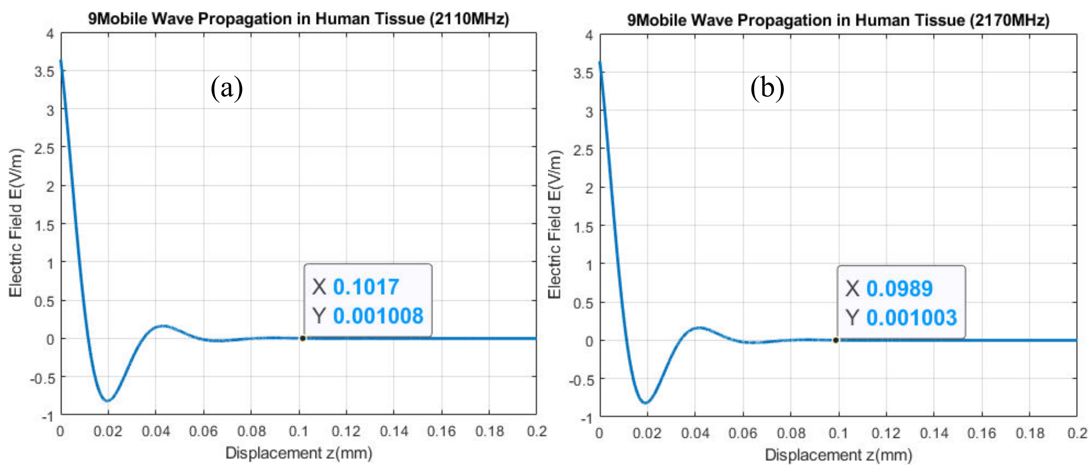

Fig. 7 Wave propagation in human tissue from 9Mobile (a) 2110MHz (b) 2170MHz

When the frequency of the propagating wave is increased to 30GHz, one can see a marked difference in the penetration depth into the skin. The penetration depth is vastly reduced in this case as seen in Fig.8. The increased frequency has caused a reduction of the wave penetration to a value very close to the surface of the skin as compared with curves of Figs. 2 to Fig.5. What is also observed here is that the magnitude of the electric field ($\boldsymbol{E}$) does not alter the penetration as can be seen in Fig.6. In Fig.6 (a) the electric field which a particular wave attenuates to zero in human tissue.

Displayed in Table 1 are the lower and upper frequencies for the frequency bands used by the four major GSM service providers in Nigeria. This shows the network providers, frequency bands, wavelengths, penetration depths and percentage penetration. This table is very important because it shows clearly the layer of the skin, where the wave propagating in the skin tissue at a particular frequency, will completely attenuate to zero. Take for instance if the EM wave is transmitted at a frequency 2110 MHz, the wave travels through the first layer; the epidermis having a thickness band of (0.06 – 0.1) mm and in the second layer; the dermis at a 0.11% penetration.

TABLE 1 FREQUENCY BANDS USED FOR GSM WIRELESS TRANSMISSION

Network Providers	Frequency Bands (MHz)	Wavelength (m)	Penetration Depth (mm)	% Penetration (Layer of skin)
All Networks	2110 2170	0.142 0.138	0.103 0.099	100 (Epidermis) 99 (Epidermis)
Glo Ng	758 803	0.396 0.374	0.279 0.263	6.4 (Dermis) 5.8 (Dermis)
MTN Ng	2620 2690	0.114 0.112	0.081 0.079	81 (Epidermis) 79 (Epidermis)
MTN Ng	791 821	0.379 0.365	0.267 0.257	5.9 (Dermis) 5.6 (Dermis)
MTN Ng	3400 3600	0.088 0.083	0.062 0.059	62 (Epidermis) 59 (Epidermis)
Airtel and 9Mobile Ng	1805 1880	0.166 0.160	0.119 0.115	0.68 (Dermis) 0.54 (Dermis)

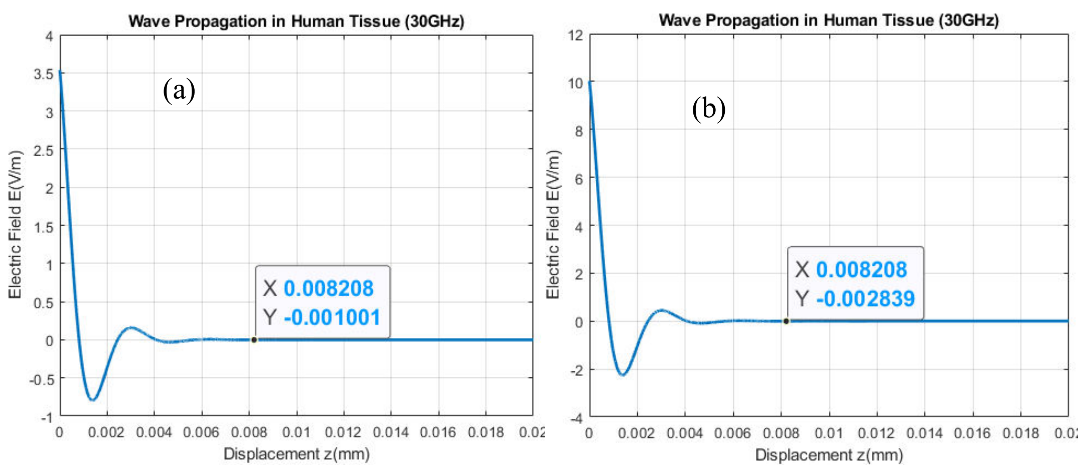

Fig. 8 Wave propagation in human tissue at 30GHz (a) 7.759 V/m (b) 20 V/m

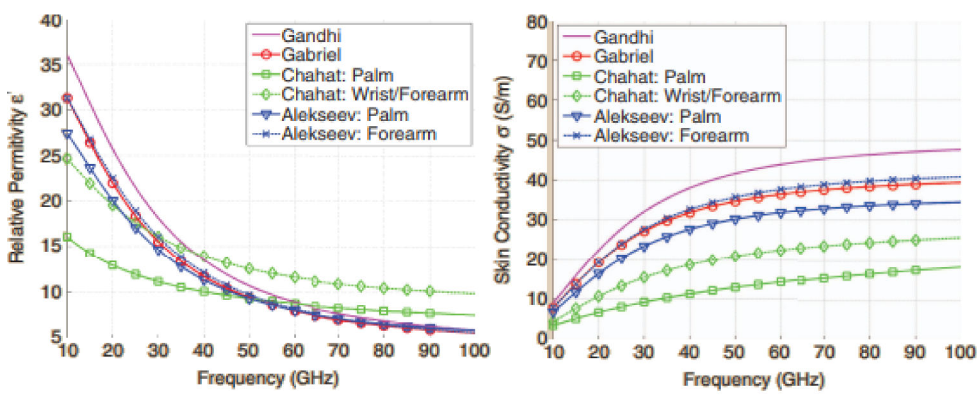

Fig. 9 Relative permittivity obtained by several researchers at frequency from 10 to 100GHz

For validation a comparative analysis of the relative permittivity, skin conductivity obtained by other investigators and oscillating wave pattern computed in this work was done. Referring to Fig. 9, measurements conducted on the skin of various researchers whose names are identified in the legends of the diagrams of Fig. 9 that show the profiles of (a) relative permittivity and (b) skin conductivity. It can be observed that the relative permittivity exhibits high values at the lower frequency and taper asymptotically as the frequency increases as seen in (a). The lower frequency indicated in Fig. 9 is 10 GHz. Similarly, (b) portrays how the conductivity increases rapidly from the lowest frequency of 10 GHz to higher frequency. Electric field pattern computed at 10 GHz in this work is depicted in Fig. 10(a). It can be seen that the field strength is considerably higher at 10 GHz where the relative permittivity is highest and rapidly attenuates to zero at a distance 0.0171 mm. As the frequency of the wave moves further upward to 40 GHz in Fig. 10(b), it is clearly seen that the penetration depth has reduced to 0.06668 mm. In fig.10(c), the frequency has gone up to 70 GHz, further reducing the penetration depth to 0.00387 mm and finally increasing the frequency to 100 GHz will further push the towards the surface of the skin at a depth of 0.002708 mm, when compared to the dimension of the skin in Fig. 1, the relative permittivity tapers to zero. Identically, conductivity profiles rapidly increase from the lowest frequency of 10 GHz to higher frequencies leading to a higher absorption of the electric field oscillations. Hence, the damping oscillations of the electric field occurs. This lends credence to the validity of the electric filed patterns computed in this work.

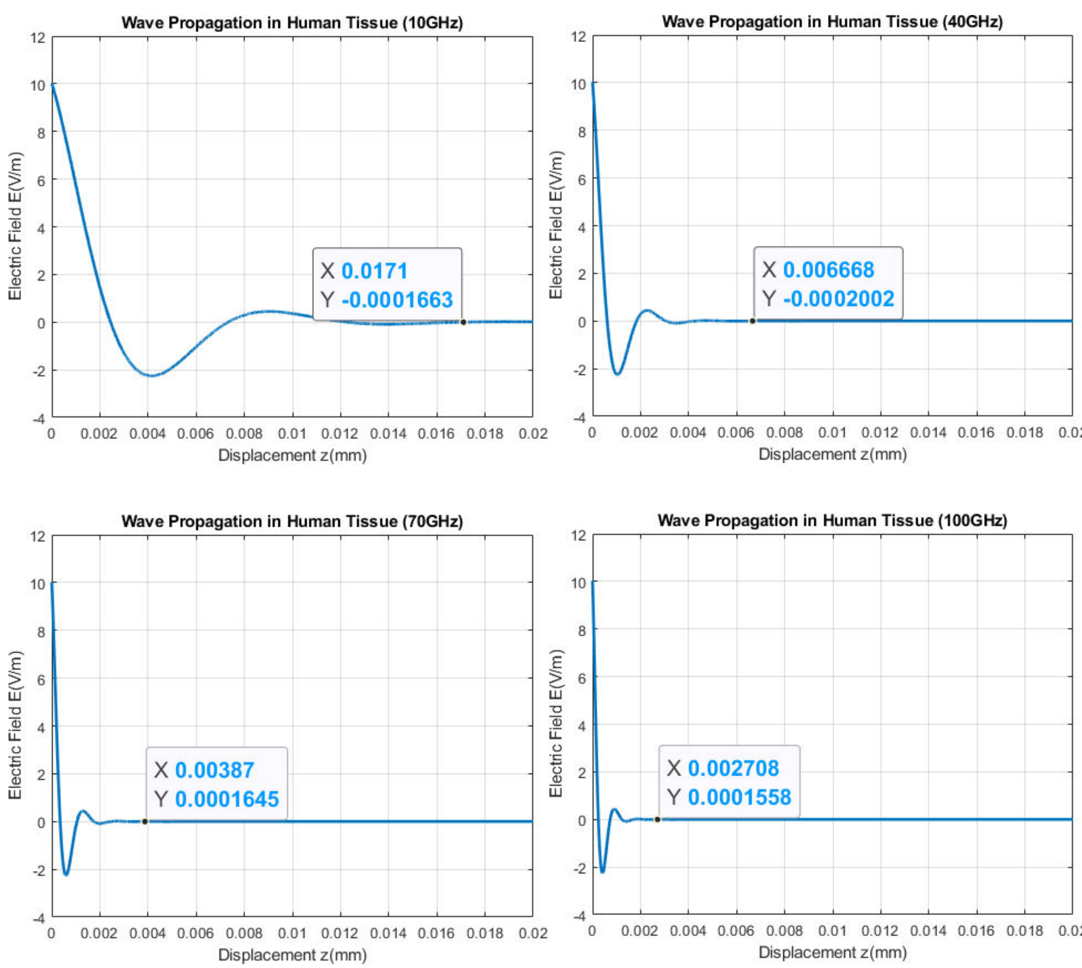

Fig. 10 Penetration depths of varying frequencies, 10 Ghz, 40 Ghz, 70 GHz and 100 GHz

V. CONCLUSION

Based to the analysis conducted for this study, the operating frequency rather than the electric field strength influences how deeply an EM wave penetrates human skin. This is proven by the fact that there is no difference in the penetration depth between the measured electric field values and the theoretical data used to plot for a specific frequency. These validate the fact that frequency alone is responsible for the penetration depth of EM waves into the human tissue**.**

One can therefore realize from the foregoing that at frequencies lower than the microwave bands, such as the radio frequencies, the waves would penetrate deeper into the human tissue, well above the values observed for the microwave bands. Thus, radiofrequency EM waves penetrate deeper than microwaves while the depth of penetration of microwaves is longer than those of mmWave and THz waves. In other words, EM waves at lower frequencies penetrate the epidermis deeper than those at higher frequencies. This allays the fear that licensing and roll out of 5G telecommunication services as being planned by the government portends grave danger to the citizenry.

The results also showed that the wave, depending on the frequency of the wave, attenuates within the first layer, the epidermis having a maximum thickness of 0.1 mm and the second layer which is the dermis which has a maximum thickness of 2.8 mm in the human skin. This is an indication that those people bleaching their skins could be removing the top layer, the epidermis of their skin, thereby allowing a further penetration of the wave into their skin.

REFERENCES

Akpolat, V. Akdag, M. Z. Dasdag, S. Alkis, M. E. Biglin, H. M. Yegin, K. and Yavas, M. C. (2019). Effect of 900-, 1800-, and 2100-MHz Radiofrequency Radiation on DNA and Oxidation Stress in Brain. *Electromagnetic Biology and Medicine*.

Batool, S. Bibi, A. and Mangini, F. (2019). Benefits and Hazards of Electromagnetic Waves, Telecommunication, Physical and Biomedical: A Review. *European Review for Medical and Phamacological Science, 23*, 3121-3128.

Brown, T. W. C. Jamshed, M. A. and Heliot, F. (2020). A Survey on Electromagnetic Risk Assessment and Evaluation Mechanism for Future Wireless Communication Systgems. *in IEEE Journal of Electromagnnetics, RF and Microwaves in Medicine and Biology, 4*(1), 24-36.

Dave, S. Dubey, A. Macwan, S. and Modi, H. (2015). 5G Cellular Communication System with Millimeter Waves: Study of Requirements, Hardware and Biological Effects. *2015 IEEE International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN)*, 285-289.

Gabriel, C. Gabriel, S. and Corthout, E. (1996). The Dielectric Properties of Biological Tissues: I. Literature Survey. *Physics in Medicine & Biology, 41*(11).

Gandhi, O. P. and Riazi, A. (1986). Absorption of Millimeter Wave bby Human Beings and its Biological Implications. *IEEE Transactions on Microwave Theory and Techniques, 34*(2), 228-235.

Hu, C. Zuo, H. and Li, Y. (2021). Effects of Radiofrequency Electromagnetic Radiation on Neurotransmitters in the Brain. *Frontiers in Public Health , 9*, 1-15.

Jeong, N. S. Ou, Y. Tassoudji, A. Dunworth, J. Koymen, O. and Raghavan, V. (2018). A Recent Development of Antenna-in-package for 5G Millimeter Wave Application (Invited paper). *2018 IEEE 19th Wireless and Microwave Technology Conference (WAMICON)*, 1-3.

Julian, B. Andrea, D. Iman, F. Lourdes, F. Sammut, C. V. (2020). Application Artificial Neural Networks for Accurate Determination of the Complex Permittivity of Biological Tissue. *Sensors Basel, 20*(16).

Lewandovski, A. Szyplowska, A. Kafarski, M. Wilczek, A. Barmuta, P. and Skierucha, W. (2017). 0.05-3 GHz VNA Characterization of Soil Dielectric Properties Based on the Multiline TRL Calibration. *Meas. Sci. Technol, 28*(2).

Lopez-Djeda, W. Pandey, A. Alhajj, M. and Oaklay, A. M. (2021). Anatomy, Skin (Integument). *StatPearls Publishing LLC*.

Ma, L. Shen, H. B. and Liu, L. (2013). Analysis of Wave Propagation on Human Body Based on Stratified Media Model. *Journal of Central South University, 20*, 3545-3551.

Miklavcic, D. Pavselj, N. and Hart, F. X. (2006). Electrical Properties of Tissues. *Wiley Encyclopedia of Biomedical Engineering*.

Odemer, R. and Odemer, F. . (2019). Effects of radiofrequency electromagnetic radiation (RF-EMF) on honey. *Science of the Total Environment, 661*, 553-562.

Sehrai, D. A. Altaf, A. Abdullah, M. Tufail, M. Irfan, M. Kiani, S. H. Glowacz, A. Rahman, S. Muhammad, F. (2020). A Novel, High Gain Wideband MIMO Antenna for 5G Millimeter Wave Application. *Electronics, 9*(6).

Simko, M. and Mattsson, M. O. (2019). 5G Wireless Communication and Health Effects - A Pragmatic Review Based on Available Studies Regarding 6 to 100GHz. *Int. J. Environ. Res. Public Health*.

Yinliang, D. Rashed, E. A. and Hirata, A. (2020). Assessment of Absorbed Power Density and Temperature Rise for Nonplanar Body Model Under Electromagnetic Exposure Above 6 GHz. *Physics in Medicine and Biology, 65*(22).