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EXPERIMENTAL INVESTIGATION OF ELECTROMAGNETIC WAVE ABSORPTION FROM SELECTED WIRELESS DEVICES

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Abstract
Electromagnetic fields absorbed from selected devices (telecommunication base station, laptop computer, Bluetooth ear-bud, Wi-Fi Router, TV receiver and Android iPhone) operating within the S-Band frequency were investigated. The fields radiated by each of the aforesaid devices were measured using an SMP2 RF meter at varying distances from the sources. The specific absorption rates for different class ranges of body mass were evaluated from the measured radiated fields at varying distances and compared with the ICNIRP standards for maximum exposure limits. The obtained results established that people staying at a distance of 1 m or less from each of the Wi-Fi routers, iPhone 11, and telecommunication base stations absorbed fields above the permissible level specified by the ICNIRP. In addition, individuals with lower BMI class ranges are more prone to high radiation absorption. This is obvious because only 8 kg/m^2 and 16.45 kg/m^2 BMI class averages have SAR values above the European standard of 0.08 W/kg. This indicates that moderately and severely thin individuals, including children, are at risk of higher radiation exposure when they remain in close proximity to these devices. Hence, every individual who interacts with these devices daily should be aware of the associated risks and take precautions.

1. INTRODUCTION

Electromagnetic (EM) fields are produced whenever electricity is generated or transmitted. Every current-carrying conductor produces a magnetic field around it, the magnitude of which depends on the amount of current flowing through it. Advances in electronics and communication have led to an increasing interaction of humans with EM fields, be it at homes, work places, markets, and even at places of worship. Wireless devices like smart

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meters, Wi-Fi routers, radio and TV transmitters and receivers, and cell phones are examples of devices that radiate free electromagnetic energy into the air space. It is noteworthy that most of these devices radiate EM waves at a frequency high enough to be classified as ionizing. How safe are we from the bombardment of EM waves? To answer this question will require an assessment of the level of compliance with EM absorption as specified by relevant agencies. Agencies such as the World Health Organization (WHO), The International Commission on Non-Ionizing Radio Protection (ICNIRP) and professional body like Institute of Electrical and Electronics Engineers (IEEE) have measures in place to safeguard the populace from the health risks associated with radiation from electrical and electronic devices that are being introduced into the market. The regulation often comes in terms of the Specific Absorption Rate (SAR) figure specification.

With many devices around us at home, offices, neighbourhood etc., each with its own SAR figures, is it possible to maintain the radiation level within the safe limit for human health? Besides electronics and electrical gadgets, many household devices like microwave oven are also potential sources of EM radiation. In as much as one cannot eliminate these devices and at the same time, one cannot take health for granted, there is a need for the investigation of radiations from common devices operating at high frequency bands of the EM spectrum that we interact with on a daily basis to determine the level of compliance with the SAR limit. This needs to determine the level of compliance to the SAR limit due to human exposure to EM radiation from diverse sources in the environment justify the necessity for this study. Results from this study will enable deductive inference that will aid the setting of safety precautions for humans interacting with these devices.

2. LITERATURE REVIEW

The S-band is a portion of the EM wave spectrum that ranges from 2 to 4 GHz. It crosses the boundary between the ultra-high frequency (UHF) and super-high frequency (SHF) bands at 3 GHz. The S-band also contains the 2.4–2.483 GHz frequency spectrum reserved for Industry, Scientific, and Medical (ISM) purposes, excluding applications for telecommunication purposes. Thus, the S-band falls within the microwave frequency band. Microwave radiation is emitted by various computing, communications, and other devices. In many transport, industrial, and medical contexts, humans are in constant interaction with several of these sources of emission. Pseudo-reverberant conditions are created in which absorption by human bodies can form a significant loss mechanism. The amount of energy stored, and hence the field intensities in these environments, depend on the nature of EM absorption by the human body; therefore, quantifying human absorption at those frequencies is necessary for estimations and decision-making on possible safety measures.

According to the WHO [1], convincing evidence to justify the adverse health effect of low-level EM fields does not exist, and if such evidence exists at all, they are 'likely' to be 'minimal' compared to other health risks to which humans are exposed in everyday life. Without mincing words, this statement is without any ambiguity and reveals that there are accompanying health risks from exposure to EM radiation, the level of which depends on the strength of the incident EM field. Scientific studies have shown that strong RF signals result in harmful heating effects on the human body [2, 3], including hypersensitivity, depression, lethargy, cataract, low birth weight, and cancer.

Gregory [4], while attempting to quantify EM radiation absorption by the human body, for simulating its effect on the environment, submitted that to measure absorption, it is first necessary to define or identify parameters that need to be measured. Two parameters identified in that regard were SAR (measured in W/Kg) and Absorption Cross-Section (ACS). The SAR quantifies the amount of power from the EM wave that is absorbed per unit mass of an absorber such as a human body, while ACS is a measure of EM absorption by the whole body of an absorber. It is defined as the EM power absorbed by the object divided by the power density of the incident EM wave.

Zaman [5], while investigating the consequences of EM radiation on the sensory system, reported that the use of electronic gadgets makes life easier; however, they negatively impact human health. Such negative impacts identified in the study include psychological issues, impairments of bone and cartilage formation, impairments of testicles and spermatogenesis, and effects on the lymphatic system and brain tumours. In another study, Akbaba *et al.* [6] established that while telecommunication devices, including mobile phones, Wi-Fi routers, computer systems, and television sets, have proved to be revolutionary in terms of communication around the globe in real time, they are usually accompanied by EM radiation hazards. The human body absorbs these radiations, and long-term exposure can result in different diseases like cancers, mental disorders, neurological illnesses, fatal abnormalities, and cardiovascular diseases.

The EM radiation exposure level from the base station was the subject of the investigation reported in [7], where the study developed a spatial model for the analysis of EM radiation on human health. The investigators further submitted that the EM radiation from the base station attacks human body cells by removing calcium ions. Varghese *et al.* [8] studied the effect of EM radiation on brain conditions and conducted experiments with laboratory rats. It was found that exposure of rodents to EM radiation (from 2.45 GHz and above) causes many changes to the rat brain, of which a decrease in brain antioxidants was the dominant effect.

In a similar study, Oh *et al.* [9] used laboratory rats to investigate the effects of EM radiation from mobile phones on spermatogenesis in the 4G LTE era. A controlled experiment was carried out on four-week-old, 20 male Sprague-Dawley rats. Findings from the investigation revealed that exposure of the rats to EM radiation from mobile phones for a long time negatively affected their spermatogenesis. Specifically, sperm and Leydig cell counts were significantly decreased after exposure. This finding suggests that continuous and prolonged cell phone use could be hazardous for fertile men, especially adolescent men. Based on findings from the investigation of the impacts of mobile phone base station antennas on human health, Subhan *et al.* [10] reported that people living near such antennas were probably at a high risk of diseases, including cardiovascular problems, skin diseases, irritability, visual disruptions, hearing problems, and depression.

Taye *et al.* [11] studied the effect of EM wave radiation on bee colony collapse. They observed that owing to heavy EM pollution; bees find it difficult to locate their hives, particularly bee hives that are close to telecommunication towers. They opined that the sudden loss of bees in the US is traceable to the increasing influence of EM wave pollution. This phenomenon is known as Colony Collapse Disorder (CCD), where bees cannot detect the right way to find their hive due to persistent EM wave pollution.

The use of electronic devices and modern communication devices generally have negative effects on the user [12]. These negative effects are noticeably significant in the Radiofrequency (RF) band of the EM spectrum, which is used for communications, radio and TV broadcasting, cellular networks, and indoor wireless systems. Authors in [12] observed that along with the widespread use of technological products in daily life, the biological effects of EM wave radiation on the well-being of humans have begun to be more widely discussed. They admitted that there is no direct evidence of the hazardous effects on human health incurred by low-frequency radiofrequency waves. However, studies have shown that radiofrequency waves have delirious effects on human health at relatively higher frequencies.

EM radiation is generally grouped into two categories: ionizing and non-ionizing. Ionizing radiation has high energy with frequencies ranging from 1 PHz (petahertz) to 10 ZHz (zettahertz) and includes X-rays and gamma rays. Non-ionizing radiations have a frequency in the range of 1 to 1000 THz (terahertz) and consist of Microwave (MW), Infrared (IR), Visible Light (VL), and ultraviolet light (UV). While ionizing radiation has the capacity to cause changes in the structure of atoms or molecules and the structure of DNA in living organisms by ionization, non-ionizing radiation generally does not pose such a threat. Moon [13] established the vulnerability of the nervous systems of children to EM field radiation compared with that of adults. Hence, it becomes necessary to investigate the absorption limit of individuals relative to their weight and height to make informed decisions on how to abate the adverse effects of EM fields in humans.

3. MATERIALS AND THE METHOD

Few materials employed during this investigation are:

i) SMP 2 Wave-control field strength meter for the EM field measurement. It is equipped with an omnidirectional probe antenna that is frequency adjustable and suitable for measuring EM field radiation at a distance.

ii) Retractable 5-m tape is required for the measurement of distances at which the EM field measurements are to be taken.

iii) Few devices operating within the S-band that radiate EM waves at different locations (offices, homes, and neighbourhood) of possible human interaction were selected. Six devices were selected: mobile phone (iPhone 11), Wi-Fi router, radio base station, laptop computer, LCD TV screen, and Bluetooth earbuds.

The SAR figure, measured in W/Kg, is expressed as follows:

$$SAR = \frac{P_{abs}}{m} \quad W/kg \tag{1}$$

where P_{abs} is the power absorbed from the EM radiation in W and m is the mass in kg. The electric field intensity E in V/m of radiation from each of the selected devices operating within the S-band frequency is measured. Since the radiation from the devices is a continuous-wave transmission and assumed to be of constant amplitude, the corresponding power density P_{fd} in $\left(W/m^2\right)$ is obtained using

$$P_{fd} = \frac{E^2}{\eta} \quad W/m^2 \tag{2}$$

provided η is the intrinsic impedance of the free space whose value is 377 Ω.

Seven standard ranges of body mass index (BMI) classes in kg/m^2 have been specified [14]. Table 1 presents the details of the BMI classifications according to the WHO standard.

Category	BMI Class $\left(kg/m^2\right)$	
	Range	**Average (BMI_{ave})**
lower weight (Severe thinness)	< 16.0	8.00
lower weight (Moderate thinness)	16.0 – 16.9	16.45
lower weight (Mild thinness)	17.0 – 18.4	17.70
Normal weight	18.5 – 24.9	21.70
Overweight (Pre-obese)	25.0 – 29.9	27.45
Obese (Class I)	30.0 – 34.9	32.45
Obese (Class II)	35.0 – 39.9	37.45

Table 1: BMI categories based on class range

The use of the value of the computed power density in (2) and the corresponding BMI class average (as shown in Table 1) allows the determination of the corresponding SAR figure from the measured values of fields radiated by each of the selected devices using (1). In other words,

$$SAR = \frac{P_{fd}}{BMI_{ave}} \; W/kg \tag{3}$$

The obtained results are then compared with the ICNIRP standard to make informed deductions. It should be noted that ICNIRP set the Whole-Body SAR limit for public exposure as 0.08 W/kg for a continuous timing of 6 min as the European standard; this value is used as the benchmark in this work. For near-field measurements, the distance D of the receiving device from the EM field source is valid if

$$D << \frac{\lambda}{2\pi} \tag{4}$$

and

$$v = f\lambda \tag{5}$$

where (v, f, λ) are the velocity, frequency, and wavelength of the electromagnetic wave.

For operating frequencies, f = 2-4 GHz, the corresponding wavelengths range between $7.5 \leq \lambda \leq 15$ cm. Consequently, the near-field distance is given as $1.2 \leq D \leq 2.4\, cm$, if use is made of (4). Thus, in this work, radiated field strengths are measured for both near and far fields at four different distances from the radiation sources (each of the selected devices): 0.0, 0.5, 1.0, and 2.0 m, and the corresponding power density is determined. From these values, the corresponding body mass index class averages based on WHO categorization were determined at different selected distances from the devices.

4. RESULTS AND DISCUSSION

Table 2 presents the results of the measured electric field intensity and the corresponding computed power density for the six devices employed in the investigation at four different distances for a 6-min continuous duration. The SAR figures for each BMI class average are computed at 0.0, 0.5, 1.0, and 2.0 m from the sources.

Table 2: Measured electric field intensities and associated power densities at different distances from devices for 6 min

	$E\ (V/m)$				$P_{fd}\ (W/m^2)$			
Devices	**0 m**	**0.5 m**	**1.0 m**	**2.0 m**	**0 m**	**0.5 m**	**1.0 m**	**2.0 m**
Bluetooth earbuds	13.2949	11.9207	10.5465	7.7981	0.4688	0.3769	0.2950	0.1613
Wi-Fi router	22.3404	19.70035	17.0603	11.7802	1.3239	1.0295	0.7720	0.3681
Radio base station	15.5933	13.6312	11.669	7.7447	0.6450	0.4929	0.3612	0.1591
LCD TV screen	10.5773	8.9431	7.3088	4.0403	0.2968	0.2121	0.1417	0.0433
iPhone 11	18.4885	16.4054	14.3223	10.1561	0.9067	0.7139	0.5441	0.2736
Dell laptop	16.0416	14.1343	12.2269	8.4121	0.6826	0.5299	0.3965	0.1877

Figure 1 illustrates Variations of SAR figures with the BMI class average at four different distances from devices for a continuous 6-min duration.

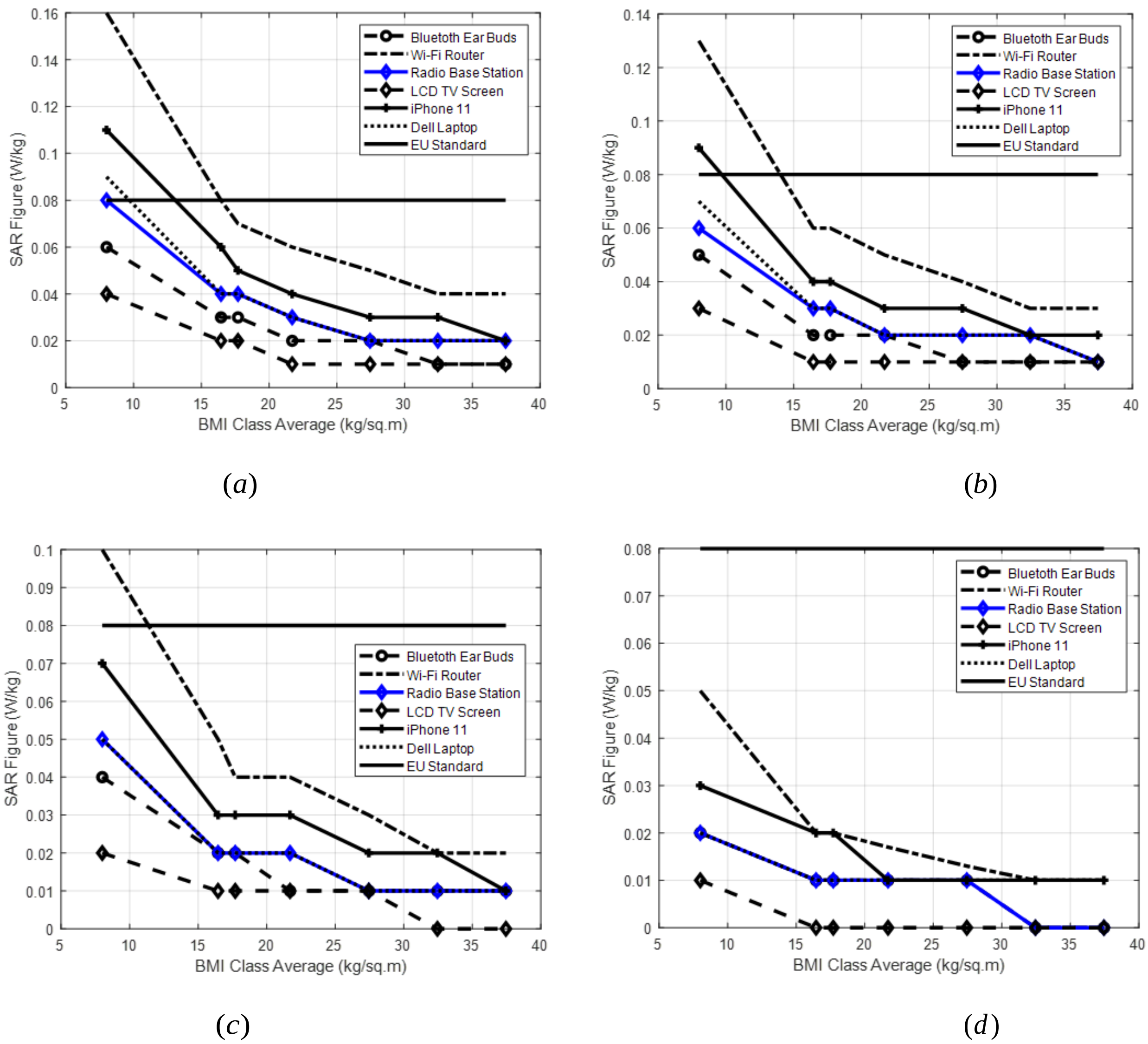

Figure 1: Variations of SAR figures with the BMI Class Averages at different distances from devices for continuous 6-min duration (a) 0 m (b) 0.5 m (c) 1.0 m (d) 2.0 m

Considering Figure 1(a) when the distance is at 0 m, it is obvious that the Wi-Fi router, iPhone 11, and Dell laptop radiate EM energy above the permissible European standard of 0.08 W/kg, although at different values of BMI class average. The Wi-Fi router has SAR figures above the standard for BMI class average of up to 16.45 kg/m^2, iPhone 11 for about 13.07 kg/m^2 while Dell laptop has up to 9.69 kg/m^2. The radio base station at 0 m radiates an EM energy of about 0.08 W/kg within a BMI class average of about 8 kg/m^2. This signifies that at near use of possible touch contact, those devices (Wi-Fi router, iPhone 11, Dell laptop and radio base station) radiate EM energy above the permissible European standard and are consequently considered hazardous to human health over time. Other devices (Bluetooth ear buds and LCD TV screen are safe because the EM energy radiated by each of the two at 0 m is below the permissible value of 0.08 W/kg for all categories of BMI class average.
The trend lines below the red line are Bluetooth Ear buds and LCD television screens. This implies that even near-use touch contact radiation from these devices is below the permissible range and safe for use.

Figure 1(b) depicts the variations of SAR figures with BMI class average at 0.5 m distance, where it is clearly shown that the Wi-Fi router and iPhone 11 radiate EM energy above the permissible European standard. Prolonged exposure to the two devices by people with BMI class averages of approximately 14 and 9.69 kg/m^2, respectively, is considered unsafe, according to the values of computed SAR figures. Other devices have SAR values lower than the European standard and are considered safe.

Figure 1(c), which depicts variations of computed SAR figures with BMI class average when the distance to radiation source is 1 m, reveals that only the Wi-Fi router is unsafe for BMI class average of up to 11.38 kg/m^2. Other devices clearly radiate EM energy at levels well below the specified European standard. In Figure 1(d), all six devices considered and investigated were found to radiate EM energy at levels far below the permissible European SAR standard value at a distance of 2 m. This indicates that at a distance of 2 m, all six devices are safe for human health irrespective of the hours of exposure.

5. CONCLUSION

The results deduced from the experiment establish that Wi-Fi routers, iPhone 11, and radio base stations radiate above the permissible SAR value set by the ICNIRP at near distances of up to 1 m. It can also be concluded based on the obtained results that individuals that fall within lower BMI class ranges are more prone to high EM energy radiation absorption from wireless devices when the separation is less than 1 m. This is evident from the fact that only at a distance of 2 m does the Wi-Fi router appear safe based on computed SAR figures. The interpretation of this is that moderately and severely thin individuals are at risk when situated within a 1-m radius in an environment that houses a Wi-Fi router. This is particularly the case with most children below 20 years of age who have a BMI class average of less than 16.75 kg/m^2, signifying that they are most at risk of radiation absorption from devices operating at S-band frequency. These results agree with the findings of Moon (2020), who submitted that the nervous system of children is more vulnerable to EM field radiation than that of adults, and such a group of human beings must be protected from exposure to EM field radiation.

With the deductions from this study work, it is recommended that every individual who uses or interacts with these devices daily should be aware of the risk of excessive exposure to hazardous radiation to their health. We also recommend that children below 20 years of age should limit their interaction with devices operating at the S-band because they are more at risk of hazardous radiation due to their relatively lower Body Mass Index.

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Ethical Consideration: This work has no conflict whatsoever with any known ethical standards that require the seeking of permission and approval.

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