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Assessment of Radio Frequency Power Density Emissions from Mobile Phones at 4G/5G Operating Frequencies in a Tertiary Institution in Delta State, Nigeria

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Abstract

The rapid increase of mobile communication devices has raised significant public health concerns regarding human exposure to radio frequency (RF) electromagnetic fields. This study presents an experimental assessment of RF power density emissions from seven commercially available mobile phone brands (Redmi, Tecno, Infinix, Samsung, Honour, Itel, and OPPO) operating on fourth and fifth generation (4G/5G) mobile networks. Measurements were conducted at two distances (10.16 cm and 20.32 cm) using a calibrated RF meter, with three replicate readings recorded per device. A total of 246 measurements were obtained and analyzed. The results show that the mean power density at 10.16 cm ranged from 2.63 mW/cm^2 (OPPO) to 6.41 mW/cm^2 (Tecno), with a mean value of 5.46 ± 6.91 mW/cm^2. At 20.32 cm, the mean power density decreased significantly, ranging from 0.28 mW/cm^2 (OPPO) to 2.34 mW/cm^2 (Honour), with a mean value of 1.34 ± 2.01 mW/cm^2. All brands displayed some degree of attenuation with increasing distance, with an average distance attenuation ratio of 4.66. At 10.16 cm, 99.2% of all measurements exceeded the 1.0 mW/cm^2 general public exposure reference level, but at 20.32 cm, only 49.2% exceeded this threshold. These findings demonstrate that RF power density from mobile phones decreases with distance following the inverse-square law, yet close exposure levels may demand precautionary measures. The study recommends the use of hands-free accessories and maintaining adequate separation distance between the device and the body to minimize RF exposure.

Keywords: Radio frequency radiation; Phone; Electromagnetic field exposure; 4G networks; Specific absorption rate; Public health

Introduction

The rapid expansion of mobile telecommunications infrastructure and the ubiquitous adoption of smartphones have fundamentally transformed modern society. As of 2024, global mobile subscriptions exceed 8.5 billion, with 4G Long-Term Evolution (LTE) networks and more recently 5G serving as the dominant wireless communication standard in most regions (Ericsson, 2024). Mobile devices

operate by transmitting and receiving radio frequency (RF) electromagnetic waves between 700 MHz to 2.6 GHz spectrum, with typical handset output powers ranging from 125 mW to 2 W depending on network conditions and proximity to base stations (Hirata et al., 2008). When the human body is exposed to RF electromagnetic fields, a portion of the incident energy is absorbed by biological tissues, resulting in localized heating (Ijabor et al., 2023). The specific absorption rate (SAR), defined as the power absorbed per unit mass of tissue (W/kg), serves as the primary dosimetric quantity for assessing RF exposure health risks (Hamed & Maqsood, 2018; Karimian et al., 2021). Regulatory bodies including the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the Institute of Electrical and Electronics Engineers (IEEE), and the Federal Communications Commission (FCC) have established exposure guidelines limiting the spatial-peak SAR to 2 W/kg averaged over 10 grams of tissue for the general population (ICNIRP, 2020; IEEE, 2019). These SAR limits correspond to equivalent power density thresholds of approximately 1.0 mW/cm^2 for frequencies within a range of 1.5-3.0 GHz (FCC, 1997).

Despite compliance with international standards at the device certification stage, human exposure varies considerably depending on usage patterns, network signal strength, device antenna design, and the distance between the phone and the user (Chowdhury et al., 2018). Previous simulation studies have demonstrated that SAR values in the human head can reach 15.45 W/kg when the device is held directly against the tissue, far exceeding safety guidelines. However, increasing the distance to >2 cm reduces SAR to safe levels (Sallomi & Ahmed, 2023). While computational modeling provides valuable insights into electromagnetic absorption patterns, empirical measurement studies characterizing actual power density emissions from commercially available devices remain essential for validating theoretical predictions and informing public health policy.

Several researchers have investigated RF emissions from mobile phones using experimental approaches. Sallomi and Ahmed (2023) employed ANSYS HFSS software to simulate SAR distributions in phantom head and body models exposed to a planar inverted-F antenna (PIFA) operating at 2.6 GHz, demonstrating that skin and fat tissues exhibit the highest absorption at zero separation distance. Rashid and Song (2019) analyzed biological effects of cell phone radiation using SAR and thermoregulatory response models. Other studies have focused on SAR reduction techniques, including artificial magnetic conductor-backed antennas and metamaterial shields (Hamadi et al., 2020; Hazarika et al., 2020). However, there exists a gap in comprehensive experimental surveys comparing RF power density emissions across multiple popular mobile phone brands at selected distances. The present study addresses this gap by systematically measuring RF power density from 123 different mobile phones representing seven major brands, at two relevant distances (10.16 cm and 20.32 cm) corresponding to typical handset-to-torso and handset-to-head separations during active use. The objectives of this work are: (i) to quantify and compare RF power density emissions across brands, (ii) to characterize the distance-dependent attenuation of RF fields, and (iii) to evaluate measured values against established exposure reference levels.

Material and Methods

RF power density measurements were performed using a calibrated RF field strength meter capable of detecting electromagnetic radiation in the 50 MHz to 3.5 GHz frequency range, encompassing all major 4G/5G LTE operating bands. The instrument features a tri-axial isotropic probe that measures the root-mean-square (RMS) power density in units of milliwatts per square centimeter (mW/cm^2) with a resolution of 0.001 mW/cm^2 and an expanded measurement uncertainty of ±1.5 dB (k = 2). Prior to data collection, the meter was calibrated against a traceable standard and zeroed in a low-RF environment to establish baseline readings.

Mobile Phone Samples

A total of 123 mobile phones were tested, encompassing seven commercially available brands widely sold in various markets: Redmi (n = 51), Tecno (n = 25), Infinix (n = 19), Samsung (n = 9), Honour (n = 11), Itel (n = 6), and OPPO (n = 2). The sample included various models released between 2015 and 2025, all configured to operate on 4G/5G LTE networks at the time of measurement. Devices were selected based on market segments, from entry-level to mid-range smartphones. Each device was fully charged, ensured to be operating on a single active SIM card from a local 4G/5G network operator, and placed in normal operating mode with screen brightness set to 50%.

Experimental Protocol

Measurements were conducted in the Science Technology Laboratory of Delta State Polytechnic, Ogwashi-Uku, Delta State with minimal external RF interference. Background electromagnetic field levels were verified to be below 0.001 mW/cm^2 across all relevant frequencies before testing. The experimental setup consisted of a non-conductive mounting platform with the mobile phone placed on it in a vertical orientation, with the RF probe positioned at two varying distances from the device antenna region. These distances were selected to approximate typical separations during handheld voice calls and texting/browsing scenarios, respectively (Wang, 2020). The phone was placed on the mounting platform and allowed to operate on the 4G/5G network with a continuous data transmission session which was initiated by streaming high-definition video content to ensure sustained RF output at maximum typical power. The RF probe was positioned perpendicular to the phone's rear surface (antenna side) at the chosen distances and three independent power density readings were recorded, each at 20 seconds interval to account for temporal variability in network transmission power.

The arithmetic mean of the three readings was computed to represent the average power density for that device distance combination. All measurements were performed at room temperature and relative humidity of 45-55%. The probe was repositioned between replicate readings to minimize systematic positional errors.

Data Analysis

Descriptive statistics (mean, standard deviation, minimum, maximum, and percentage exceeding reference thresholds) were computed for each brand and distance category. The distance attenuation ratio was calculated as the quotient of mean power density at 10.16 cm divided by mean power density at 20.32 cm for each brand. Statistical comparisons between distances were performed using paired-sample analysis where applicable. All computations were executed using standard statistical software, with significance set at $p < 0.05$.

Results and Discussion

Overall Power Density Emissions

A total of 246 measurements were obtained from 123 mobile phones across seven brands. Table 1 presents the descriptive statistics for RF power density at each distance and brand combination. Figure 1 illustrates the mean power density by brand and distance, the comparative attenuation between distances, and the computed attenuation ratios.

Brand	*Distance (cm)*	*N*	*Mean ± SD*	*Min*	*Max*	*> 1.0 mW/cm² (%)*
Redmi	10.16	51	5.80 ± 10.11	0.005	74.605	98.0
Redmi	20.32	51	1.30 ± 1.46	0.004	7.299	48.0
TECNO	10.16	25	6.41 ± 4.40	1.708	23.983	100.0
TECNO	20.32	25	1.23 ± 0.89	0.038	4.271	56.0
INFINIX	10.16	19	5.25 ± 2.14	1.897	9.074	100.0
INFINIX	20.32	19	1.38 ± 1.55	0.005	7.137	63.2
SAMSUNG	10.16	9	4.03 ± 1.33	2.332	6.554	100.0
SAMSUNG	20.32	9	0.91 ± 0.57	0.138	1.725	33.3
HONOUR	10.16	11	4.52 ± 2.17	1.888	7.633	100.0
HONOUR	20.32	11	2.34 ± 5.51	0.010	18.804	36.4
ITEL	10.16	6	4.00 ± 1.81	1.459	6.220	100.0
ITEL	20.32	6	1.13 ± 0.47	0.586	1.700	50.0
OPPO	10.16	2	2.63 ± 0.95	1.956	3.299	100.0
OPPO	20.32	2	0.28 ± 0.14	0.183	0.381	0.0

Table 1: RF power density measurements by brand and distance (mW/cm^2).

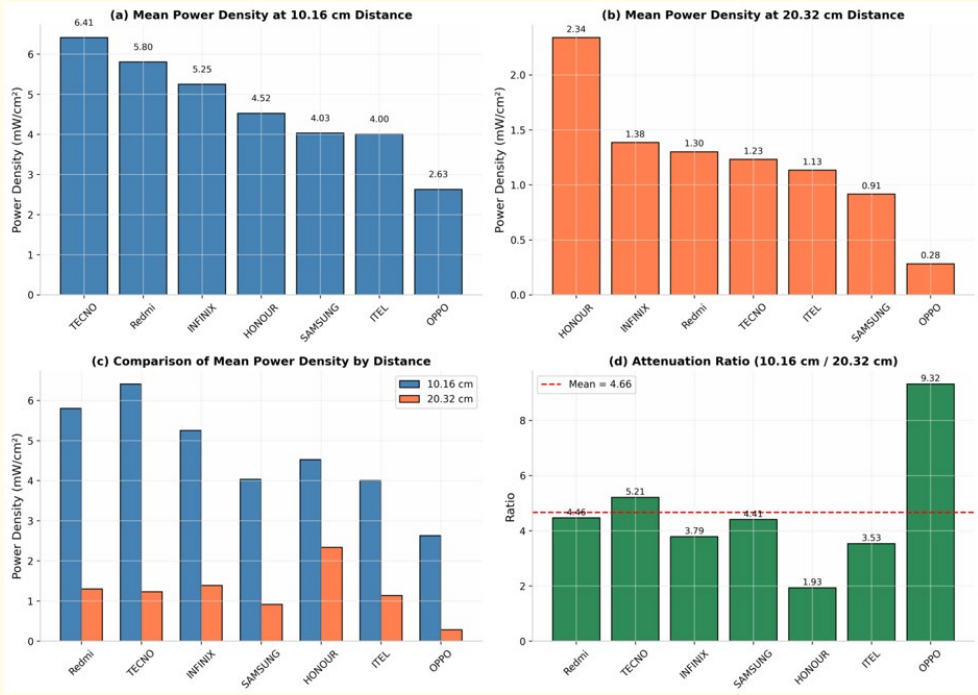

Figure 1: Comparative analysis of RF power density emissions by mobile phone brand: (a) mean power density at 10.16 cm distance; (b) mean power density at 20.32 cm distance; (c) side-by-side comparison of mean power density at both distances; (d) computed attenuation ratio (10.16 cm / 20.32 cm) for each brand, with the dashed line indicating the overall mean ratio of 4.66.

At the 10.16 cm distance, the overall mean power density across all brands was 5.46 ± 6.91 mW/cm^2 (range: 0.005-74.61 mW/cm^2). Tecno devices recorded the highest mean emission (6.41 mW/cm^2), followed by Redmi (5.80 mW/cm^2) and Infinix (5.25 mW/cm^2). OPPO exhibited the lowest mean power density at this distance (2.63 mW/cm^2). The substantial standard deviations observed for Redmi (±10.11 mW/cm^2) and Tecno (±4.40 mW/cm^2) reflect considerable inter-device variability, likely attributable to differences in specific model antenna designs, network signal conditions during measurement, and manufacturing tolerances.

At the 20.32 cm distance, the overall mean power density decreased markedly to 1.34 ± 2.01 mW/cm^2 (range: 0.004-18.80 mW/cm^2). Honour showed the highest mean at this distance (2.34 mW/cm^2), though this value was heavily influenced by a single outlier measurement; the median was considerably lower. OPPO again exhibited the lowest mean emission (0.28 mW/cm^2). The pronounced reduction in mean values between the two distances averaging a 4.66-fold decrease confirms the expected inverse-square-law dependence of power density on distance from an isotropic radiator.

Distance-Dependent Attenuation

Figure 1(d) presents the brand-specific attenuation ratios (power density at 10.16 cm divided by power density at 20.32 cm). The mean attenuation ratio across all brands was 4.66, with individual brand values ranging from 1.93 (Honour) to 9.32 (OPPO). For an ideal isotropic radiator in free space, a doubling of distance should produce a four-fold (6 dB) reduction in power density. The observed mean ratio of 4.66 is therefore consistent with theoretical expectations, with minor deviations attributable to the non-isotropic radiation patterns of mobile phone antennas, near-field coupling effects at 10.16 cm, and multipath interference in the laboratory environment. OPPO exhibited the highest attenuation ratio of 9.32, suggesting that this brand's antenna radiation pattern is particularly

directional or that the device incorporates more effective antenna impedance matching at lower output powers. Conversely, the lower ratio of 1.93 recorded for Honour indicates less distance sensitivity, which may be due to a random movement pattern of radiation or higher baseline transmission power at greater distances.

Comparison with Exposure Reference Levels

Figure 2 illustrates the distribution of power density measurements for each brand at both distances, with a reference line at 1.0 mW/cm^2 representing the general population power density exposure limit for frequencies above 1.5 GHz (FCC, 1997; ICNIRP, 2020). At 10.16 cm, 99.2% of all measurements (122 of 123 devices) exceeded the 1.0 mW/cm^2 reference level. Every brand exhibited at least 98% of its samples above this threshold at the closer distance. This finding is significant because 10.16 cm approximates the typical separation between a mobile phone and the user's head or torso during active voice calls or handheld browsing. While power density is not directly equivalent to SAR the latter depends on tissue dielectric properties, frequency, and field polarization the elevated power density levels indicate a potential for substantial RF energy deposition in superficial tissues during typical use scenarios.

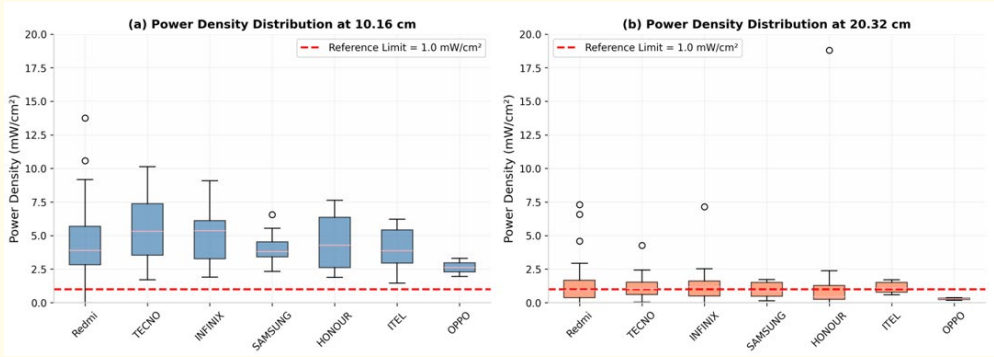

Figure 2: Box plot distributions of RF power density measurements by brand at (a) 10.16 cm and (b) 20.32 cm distances. The red dashed line indicates the 1.0 mW/cm^2 general population exposure reference level. Outliers are shown as individual circles.

At 20.32 cm, the proportion of measurements exceeding 1.0 mW/cm^2 dropped to 49.2% (60 of 122 devices). Samsung and OPPO showed the lowest exceedance rates (33.3% and 0%, respectively), whereas Tecno and Infinix maintained higher proportions (56.0% and 63.2%, respectively). This distance-dependent compliance pattern underscores the critical importance of maintaining adequate separation between the device and the body to minimize RF exposure.

Inter-Brand Variability

The results reveal notable differences in RF emission profiles across brands. At 10.16 cm, Tecno and Redmi exhibited the highest mean emissions, while OPPO and Samsung demonstrated more conservative power density levels. Several factors may be responsible for these differences: Antenna Design and Placement: Modern smartphones employ complex antenna architectures, including planar inverted-F antennas (PIFAs), coupled loop antennas, and phased arrays. The physical location of the primary antenna element relative to the device edge significantly influences the near-field power density profile (Sallomi & Ahmed, 2023; Dutta et al., 2016). Transmit Power Control: Mobile devices dynamically adjust output power based on received signal strength indicator (RSSI) values. Devices operating in areas with weaker network coverage transmit at higher power, increasing local power density. Variations in base station density and network loading across measurement sessions may have contributed to inter-brand differences. Specific Absorption Rate (SAR) Optimization: Manufacturers implement SAR mitigation techniques, including conductive shielding, ferrite sheets, and antenna loading modifications, to ensure regulatory compliance during certification testing (Hamadi et al., 2020; Hazarika et al., 2020). The effectiveness of these measures in everyday operation varies by design philosophy. Body Loss and Phantom Effects: Although mea-

surements were conducted in free space, the proximity of the user's hand and body during normal operation introduces additional absorption and detuning that can alter the effective radiated power (Mumin et al., 2018).

Implications for Public Health

The finding that nearly all devices in this study exceeded 1.0 mW/cm^2 at 10.16 cm proximity warrants careful consideration in the context of long-term, low-level RF exposure. While chronic thermal effects are unlikely at these power densities given the body's thermoregulatory capacity, the non-thermal biological effects of chronic RF exposure remain an active area of research (Hamed & Maqsood, 2018; Rashid & Song, 2019). The International Agency for Research on Cancer (IARC) has classified RF electromagnetic fields as possibly carcinogenic to humans based on limited evidence from epidemiological studies (World Health Organization [WHO], 2011). From a precautionary perspective, the major reduction in power density achieved by increasing the distance between device and body from 10.16 to 20.32 cm averaging a 4.7 fold decrease supports public health recommendations advocating for the use of wired or Bluetooth headsets to increase head and phone separation during voice calls; speakerphone mode for extended conversations; avoiding phone and body contact (e.g., trouser pockets) when the device is actively transmitting; preference for areas with strong network signals, enabling the handset to operate at lower transmit power.

Limitations

This study has several limitations that should be acknowledged. First, measurements were conducted in a laboratory environment rather than in real world usage scenarios; the presence of the user's hand, head, or body would alter the radiation pattern and absorption characteristics. Second, the phones were drawn from a tertiary institution within a geographic location and may not be representative of global device portfolios. Third, power density was measured as a scalar quantity without characterization of the vector electric field polarization or frequency spectrum composition. Finally, power density measurements do not directly translate to SAR values without detailed knowledge of tissue dielectric properties and field penetration depths.

Conclusions

This experimental study measured RF power density emissions from 123 mobile phones representing seven major commercial brands at fixed distances of 10.16 and 20.32 cm. The study revealed that the mean power density at 10.16 cm ranged from 2.63 mW/cm^2 (OPPO) to 6.41 mW/cm^2 (Tecno), with 99.2% of all measurements exceeding the 1.0 mW/cm^2 general public reference level. At 20.32 cm, mean power density decreased significantly and ranged between 0.28 and 2.34 mW/cm^2 across brands, with only 49.2% of measurements exceeding the reference threshold. All brands exhibited distance-dependent attenuation consistent with the inverse-square law, with a mean attenuation ratio of 4.66 between the two measurement distances. Phone brand variability was observed, suggesting differences in antenna design, transmit power control algorithms, and SAR optimization strategies. These findings agree with simulation-based findings that RF exposure decreases as device distance to body increases (Sallomi & Ahmed, 2023). The result calls for continued public health awareness.

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