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# Discrete Bio-Hazard Model of EM Radiation for Crowded People

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## Abstract
*This study investigates the behaviour of electromagnetic (EM) waves in densely populated environments using a Multicomponent Discrete Propagation Model (MCDM). Our analysis focuses on four critical parameters: Specific Absorption Rate (SAR), Electrical Field, Skin Depth, and Effective Radiated Power (ERP) by working on crowd densities and frequencies relevant to mobile technologies. This study is the first to employ a Propagation Model for such an analysis, offering a novel approach. Through comprehensive simulations, we explore how variations in electrical field strengths impact SAR, skin depth, and ERP. The results are compared to established safety limits for whole-body SAR exposure, providing valuable insights for guidelines. This research aims to contribute to designing future electronic devices that minimize overall RF emissions. This innovative approach has the potential to improve public confidence in the safety of wireless technologies significantly.*

**Keywords:** Multicomponent Discrete Propagation Model, Radiofrequency, Specific Absorption Rate, Skin Depth, Effective Radiated Power

## 1. Introduction
The presence of telecommunication infrastructure, devices, and daily use are undeniable facts, especially in urban areas. While we readily acknowledge non-human factors like weather and geography, the question of human interaction with electromagnetic radiation remains largely unexplored. We understand the biological effects of radiation and its interaction with devices. However, a cursory review of the literature reveals a lack of research on how human crowds might affect electromagnetic radiation flow through attenuation, absorption, scattering, distortion, or other means.

Speculation abounds regarding the use of electromagnetic radiation as a weapon, particularly in crowd control scenarios. These theories claim that radiation can be used to inflict psychological damage, control minds, or manipulate behavior. This study aims to shed light on these claims and provide some much-needed answers.

For a total coverage of telecommunication base stations are installed everywhere to assure the best performance of coverage, such stations are installed under standards of radiation required by the International Non-Ionizing Radiation Protection (ICNIRP) committee [1]. Standards set by both ICNIRP and the IEEE Standards Association (IEEE C95.1, 2019) establish limits for Whole Body Specific Absorption Rate (WBSAR) emitted by mobile phones and base stations. These limits ensure safe exposure levels. The maximum allowable WBSAR is 0.08 watts per kilogram averaged over the entire body, and the maximum localized SAR averaged over any 10 grams of tissue cannot exceed 2 watts per kilogram (W/kg).

In this study, we are going to use the Multicomponent Discrete Propagation Model developed in the paper for the sake of analyzing the behavior of electromagnetic waves in human crowded environments. The study will have four key parameters: SAR, Electrical Field, Skin Depth, and ERP [2].

### 1.1 Background of Discrete Model
A paper by introduces a novel RF propagation model specifically designed for forests. This model treats forests as collections of individual scatterers (Trees. Branches and leaves) with real-world biophysical data. This approach provides more accurate predictions of signal attenuation compared to models using a single, averaged property for the forest canopy. Studies suggest that as radio waves travel deeper into forests, unpredictable wave behavior (incoherent)

becomes more dominant. EM fields themselves can be categorized into two parts: the consistent, predictable component (coherent) and the unpredictable, random component (incoherent). Different theoretical methods are needed to analyze each type of field.

The model assumes that the forest is made up of several scatterers, each with a specific volume ($V_p$), a material property called relative dielectric constant ($\varepsilon_r$), and a radius (R) in the random medium. These scatterers are distributed throughout the forest at a constant density (ρ). The fractional volume $\delta=\rho V_n$ is so small for a typical forest around 0.1 %.

The average electrical field of scattering components is obtained in the random medium as

$$E_{pp} = exp\ (iK_{pp}L) \quad \wedge \quad p \in \{h, v\} \tag{1}$$

Where, the effective propagation constant $K_{pp}$, which describes how radio waves travel, is expressed in terms of the -scattering amplitude components obtained as.

$$K_{pp} = k_0 + \frac{2\pi}{k_0}\{\rho_t f_{pp}^{(t)} + \rho_b f_{pp}^{(b)} + \rho_n f_{pp}^{(n)} + \rho_l f_{pp}^{(l)} \tag{2}$$

Where $k_0 = \omega\sqrt{\mu_0\varepsilon_0}$ is the free space propagation constant, while L is the effective path length traveled by the wave and f is the average, considered oversize and orientation, of the scattering amplitude and $f_{pp}^{(b)}$, $f_{pp}^{(n)}$ and $f_{pp}^{(l)}$ are the average scattering amplitudes for components of volume,

The specific attenuation for horizontal (h) and vertical (v) polarization in decibels per meter (dB/m) is given as

$$A_{pp} = 8.686\ Im(K_{pp}) = 10logSAR_{pp} \tag{3}$$

We assume the forest is a vast collection of separate scatterers (like leaves, and trees here). The scatterers are spread out evenly in all horizontal directions (azimuthal). Additionally, any scattering that flips the wave's polarization (cross-polarized) cancels itself out on average. This medium is described by an "effective permittivity" and a "propagation constant" ($K_{pp}$) [2].

Equation 4 defines the correlation function (Γ) to analyze the average field (<E>) and fluctuations (E*) of the total electromagnetic field (E) which includes incoming and scattered waves. It is given by

$$\Gamma = \Gamma_c + \Gamma_i \tag{4}$$

This way of breaking down the correlation function reveals a fascinating concept: radio wave propagation through a forest can be seen as two channels working together, a coherent channel and an incoherent channel. The antenna initially transmits a well-defined wave (coherent wave). However, as this wave travels through the forest, it weakens due to two factors: absorption by the trees (ohmic losses) and scattering by the trees, which creates a new wave with random ups and downs (incoherent wave). The term helps us determine which of these two channels (coherent or incoherent) plays a dominant role in forest propagation.

On the other hand, the power of the coherent wave is given by:

$$P_c(x,\omega) = \Gamma_c(x,\omega) = \frac{A_c}{x^2}exp(-\alpha_c x) \tag{5}$$

Where $A_c$, $\alpha_c$ are respectively the excitation coefficient and the coherent attenuation constant, such that:

$$A_c = \left(\frac{\omega\mu_0}{4\pi}\right)^2 \tag{6}$$

$$\alpha_c = \rho\sigma_t \tag{7}$$

$\sigma_t$ is the total cross-section. The power of the incoherent wave is provided as

$$P_i(x,\omega) = \Gamma_i(x,\omega) = \frac{A_i}{\sqrt{x^3}}exp(-\alpha_i x) \tag{8}$$

where $A_i$, $\alpha_i$ are respectively the excitation coefficient and the incoherent attenuation constant. These are expressed as

$$A_i = \sqrt{2\pi W_0\alpha_c A_c}/\sqrt{\alpha_i} \tag{9}$$

$$\alpha_i = \alpha_c\sqrt{1 - W_0^2} \tag{10}$$

Vegetation weakening of radio waves involves two mechanisms: absorption and scattering. Albedo $W_0 = \sigma_s / \sigma_t$ , where $\sigma_s$ is the scattering cross-section, indicates the portion of wave power scattered by trees (always less than 1 due to no new energy creation). This explains why Equation 9 shows that scattering (incoherent attenuation) is weaker than absorption (coherent attenuation) within trees. Characterizing vegetation involves three key levels: Density, size, and orientation.

For electrical properties, the relative permittivity can be expressed as:

$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r'' \tag{11}$$

Where $\varepsilon_r'$ and $\varepsilon_r''$, are the real and the imaginary parts, respectively of the permittivity $\varepsilon_r$. The imaginary part is proportional to the conductivity σ through the term:

$$\varepsilon_r'' = \frac{\sigma}{\omega\varepsilon_0}\varepsilon_r \tag{12}$$

Where $\varepsilon_0$ is the permittivity of free space. The real part $\varepsilon_r'$ is usually known as the dielectric constant, while the imaginary part $\varepsilon_r'''$ is called the loss factor.

Since tree trunks are the biggest scatterers in the forest, their characteristics are described with the most detail. Interestingly, the probability of encountering a particular trunk diameter within a uniform forest (homogeneous stand or plantation) follows a normal (Gaussian) distribution.

Finally, we can describe the canopy structure. This layer of leaves and branches follows a normal (Gaussian) probability density function when considering the number of branches per unit volume (cubic meter).

Trees, despite biological differences, offer a model to understand human impact on radio waves due to their similar shapes and influence on wave propagation. A simplified analogy (tree trunk = body, branches = limbs, leaves = extremities) highlights this but requires addressing size/age variations in trees (e.g., mass/density conversion). Research neglects the interaction of radio waves with large crowds. Studying this gap could lead to improved wireless infrastructure and potentially new applications [3].

Combining Gabriel's human tissue data with Şeker's vegetation model allows us to study how electromagnetic waves interact with crowds [4]. Human bodies, like vegetation, scatter and absorb waves due to varying permittivity. This suggests humans and trees might behave similarly at large scales, making the vegetation model a valuable platform to understand crowd impact on wave propagation. Physical aspects of trees like size, shape, and orientation are crucial as in forests.

The human-vegetation analogy is helpful but requires adjustments for body size and density compared to trees. Şeker's model parameters (diameter, length, density) were adapted based on human data. Accordingly, since we are planning to simulate the human parameters, we modified the needles to fingers, leaves to palms, branches to arms, then trunks to bodies.

Consequently, we made adjustments to the diameter (D), length, and density (ρ) while probability remained unchanged. Regarding the body parameters, the data simulated in Şeker's paper [3] is kept while we performed new calculations for arms, palms, and fingers with reference to and [5,6]. Detailed work is illustrated in the Simulation section.

### 1.2 Theoretical Aspects

SAR measures electromagnetic wave energy absorbed by human tissues (W/kg). It can be averaged over the WBSAR or a smaller volume (1-gram or 10-gram average) [6]. SAR depends on the electric field strength within the body (modeled as a dielectric material) and is calculated using Equation 13 [3].

$$SAR = \frac{\sigma}{\rho}|E|^2 \; (W/kg) \tag{13}$$

E is the electrical field in [V/m], σ represents the electrical conductivity in [S/m] and $\rho$ denotes the mass density in [Kg/m3]. These parameters depend on the properties of human tissues.

According to and IEEE Standards Association (IEEE C95.1-2019) with more illustration in [7,8], WBSAR, for mobile phones and base stations, should not exceed the exposure limit, defined as 0.08 watts per kilogram and the maximum SAR value averaged over 10 grams of tissue is 2 watts per kilogram (W/kg).

Skin depth (δ) refers to the depth at which the amplitude of an electromagnetic wave has decayed to 1/e (approximately 37%) of its original value, and it is inversely proportional to the square root of the frequency (f) and conductivity (σ) of the material. This relationship can be expressed using the following equation;

$$\delta = \sqrt{\frac{1}{\sigma\pi\mu f}} \tag{14}$$

Where δ is Skin depth (meters), σ is Resistivity of the material (Ω·m), μ is Permeability of the material (H/m) (usually assumed to be the permeability of free space for most cases:

$\mu_0 \approx 4\pi \times 10^{-7}$ H/m and f is the Frequency of the wave (Hz). From another perspective, skin depth (δ) can be expressed as:

$$\delta = \frac{1}{|\alpha|} \tag{15}$$

Where α (alpha) is the attenuation constant (real part of the propagation constant) measured in reciprocal meters (1/m). Effective Radiated Power (ERP) is a constant value for an antenna at a specific frequency. Since we obtained the electrical field, we can define the effective radiated power.

$$ERP = \frac{(R*|E|)^2}{60} \tag{16}$$

This project simulates SAR in crowds exposed to 3G, 4G, and 5G frequencies using MATLAB. The program calculates SAR based on the electric field derived from the propagation constant. It also calculates skin depth and ERP across these bands. The core involves building scattering models in MATLAB using established data on human dielectric properties. The algorithm incorporates 13 elements representing obstacles within a crowd diameter, simulating wave attenuation and distortion. These elements combine to form a human model with four body types (Table 1) - torso arms, palms, and fingers and accounting for body size and type variations [5-10].

| Input parameters | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scattering components** | **D cm** | **Length cm** | **Probability** | **Density M3** | **Wh** | **Wv** | **X** |
| Finger | 1.80 | 5.98 | 0.103170 | 0.00076 | 0.47 | 0.73 | 0.600 |
| Palm of child | 6.35 | 7.50 | 0.250000 | 0.00014 | 0.06 | 0.06 | 0.600 |
| Palm of woman | 7.75 | 9.05 | 0.250000 | 0.00028 | 0.07 | 0.06 | 0.600 |
| Palm of man | 8.41 | 10.66 | 0.250000 | 0.00036 | 0.07 | 0.06 | 0.600 |
| Palm type big | 9.97 | 12.79 | 0.250000 | 0.00076 | 0.05 | 0.05 | 1.000 |
| Arm of child | 6.00 | 35.10 | 0.087500 | 0.00337 | 0.38 | 0.58 | 1.000 |
| Arm of woman | 8.90 | 47.00 | 0.287700 | 0.00828 | 0.47 | 0.73 | 1.000 |
| Arm of man | 9.00 | 54.00 | 0.310000 | 0.01069 | 0.46 | 0.74 | 1.000 |
| Arm type big | 10.50 | 60.5 | 0.316000 | 0.01588 | 0.45 | 0.62 | 1.000 |
| Body of child | 10.98 | 69 | 0.144000 | 0.02770 | 0.56 | 0.62 | 13.000 |
| Body of woman | 24.52 | 155.00 | 0.152000 | 0.04045 | 0.43 | 0.57 | 89.000 |
| Body of man | 30,89 | 177.00 | 0.384000 | 0.05076 | 0.50 | 0.63 | 900.000 |
| Body type big | 39,17 | 189.00 | 0.088000 | 0.06857 | 0.53 | 0.65 | 25.000 |

**Table 1: Input Parameters for the Human Model**

Our program already incorporates Equation (3) for the propagation constant. Utilizing this value, we will calculate Equation (2) taking into consideration that;

$$E_{pp} = E_0 + E_1 \quad (17)$$

Where $E_{pp}$ is the attenuated (absorbed, scattered) electrical field, $E_0$ is the free space electrical field and $E_1$ is the distorted (or remaining) electrical field.

### 1.3 Crowd Density Preparation

To create a realistic crowd simulation, we first calculated the available space. The chosen 6-meter diameter translates to a circle with an area of approximately 28.27 square meters. This considers both the theoretical maximum occupancy and practical limitations. The available space (28.27 m²) represents the total area for the crowd. However, to estimate the number of people, we need to consider the average personal space required for comfortable standing, which can vary based on culture and preference below is an image, as an example, that shows the distribution of people within an area.

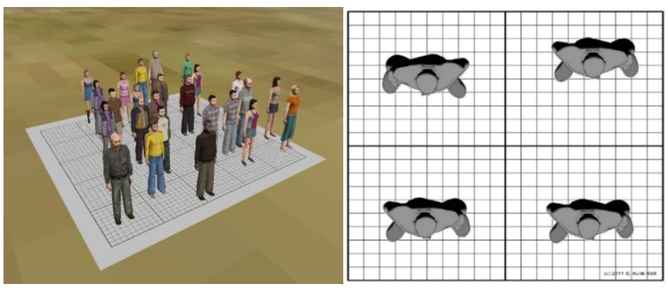

**Figure 1:** Person Per Square Meter. The left and the right images are created with one person in each square. The left image is 1 person per square meter but with random distribution (2 people in one square and 0 persons in the fourth).

Considering personal space, the 28.27 m² area could hold roughly 71 people in a high-density scenario (0.4 m²/person) like a concert, or 36 people in a more comfortable setting (0.8 m²/person) as shown below respectively for Figure 2 and Figure 3.

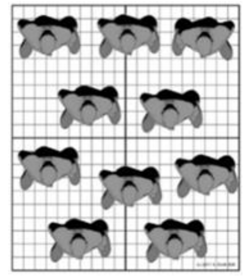

**Figure 2:** 2.5 People Per Square Metre

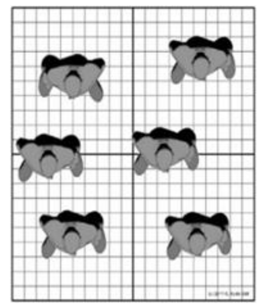

**Figure 3:** 1.25 People Per Square Metre

While 36 people represent a comfortable crowd density, it's the limit for simulations due to diminishing changes in the electrical field and SAR. Therefore, we selected densities from Table 2 for our simulations.

| Input parameters: Crowd Density | | | | | | |
|---|---|---|---|---|---|---|
| Scattering components | Number of people | | | | | |
| | 2 | 4 | 8 | 12 | 22 | 36 |
| | Density M3 | | | | | |
| Finger | 0.00038 | 0.00076 | 0.00152 | 0.00228 | 0.00418 | 0.00684 |
| Palm of child | 0 | 0.00014 | 0.00028 | 0.00042 | 0.00070 | 0.00126 |
| Palm of woman | 0.00028 | 0.00028 | 0.00056 | 0.00084 | 0.00168 | 0.00252 |
| Palm of man | 0.00036 | 0.00036 | 0.00072 | 0.00108 | 0.00216 | 0.00324 |
| Palm type big | 0 | 0.00076 | 0.00152 | 0.00228 | 0.00380 | 0.00684 |
| Arm of child | 0 | 0.00337 | 0.00674 | 0.01011 | 0.01685 | 0.03033 |
| Arm of woman | 0.00828 | 0.00828 | 0.01656 | 0.02484 | 0.04968 | 0.07452 |
| Arm of man | 0.01069 | 0.01069 | 0.02138 | 0.03207 | 0.06414 | 0.09621 |
| Arm type big | 0 | 0.01588 | 0.03176 | 0.04764 | 0.07940 | 0.14292 |
| Body of child | 0 | 0.02770 | 0.05540 | 0.08310 | 0.13850 | 0.24930 |
| Body of woman | 0.04045 | 0.04045 | 0.08090 | 0.12135 | 0.24270 | 0.36405 |
| Body of man | 0.05076 | 0.05076 | 0.10152 | 0.15228 | 0.30456 | 0.45684 |
| Body type big | 0 | 0.06857 | 0.13714 | 0.20571 | 0.34285 | 0.61713 |

**Table 2: Input Parameters for Crowd Density**

The simulations for Electrical Field, SAR, and Skin Depth were conducted at five distinct frequencies: 900 MHz, 1800 MHz, 2100 MHz, 2600 MHz, and 3500 MHz, while the ERP was performed under the frequencies 900 MHz, 1800 MHz, 2100 MHz, and 5000 MHz.

## 2. Simulation Results

### 2.1 Impact of the 12-Person Model on Coherent and Incoherent Fields

In this section, we simulated a crowd scenario with a density of 12 people. The results are presented in separate graphs for each parameter (attenuated electrical field, skin depth, and SAR). Each graph shows the coherent components of the data, visualized for both vertical and horizontal polarizations.

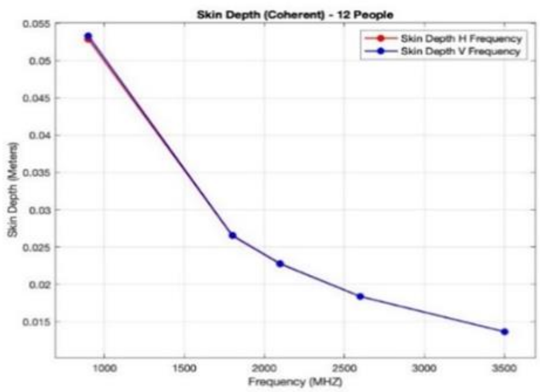


**Figure 4:** Coherent - Electrical Field Attenuation in a 12-People Crowd (6m diameter) at 900, 1800, 2100, 2600, and 3500 MHz.

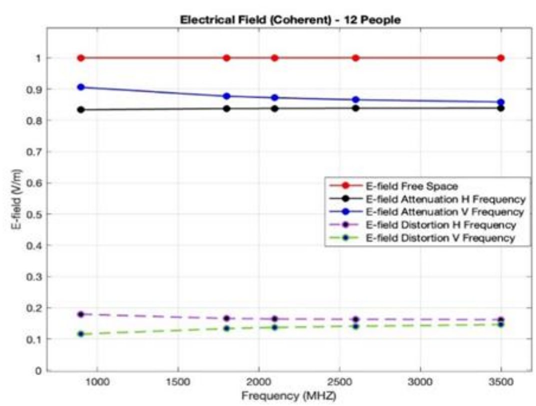


**Figure 5:** Coherent - Skin Depth in a 12-People Crowd (6m diameter) at 900, 1800, 2100, 2600, and 3500 MHz.

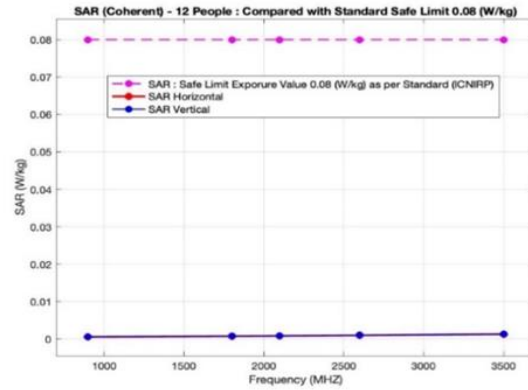


**Figure 6:** Coherent – SAR values compared with standard safe limit 0.08 (W/kg) in a 12-People Crowd (6m diameter) at 900, 1800, 2100, 2600, and 3500 MHz.

Attenuation in a 12-people Crowd (6m diameter) and Skin Depth in a 12-people Crowd (6m diameter) at 900, 1800, 2100, 2600, and 3500 MHz are similar to coherent waves. Incoherent – SAR in a 12-People Crowd (6m diameter) and SAR values compared with standard safe limit 0.08 (W/kg) in a 12-People Crowd (6m diameter) at 900, 1800, 2100, 2600, and 3500 MHz are similar to coherent wave with different values.

### 2.2 Impact of Crowd Density on Electrical Field, SAR, and Skin Depth

In this section, we tend to simulate attenuated electrical field (absorbed), skin depth, and specific absorption rate values against a number of people. To simplify plotting the results, we focused on coherent data of frequencies.

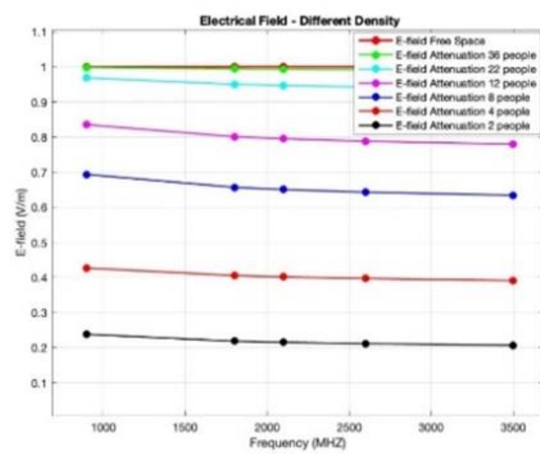


**Figure 7:** Electrical Field Attenuation in Crowds of Varying Density (6m diameter).

Skin Depth in Crowds of Varying Density (6m diameter) at 900, 1800, 2100, 2600, and 3500 are similar to coherent waves with different magnitudes.

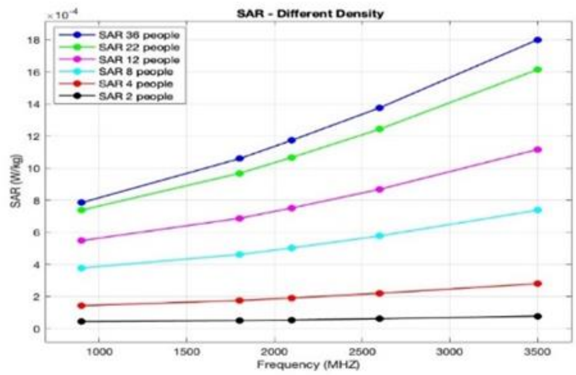


**Figure 8:** SAR in Crowds of Varying Density (6m diameter) at 900, 1800, 2100, 2600, and 3500 MHz.

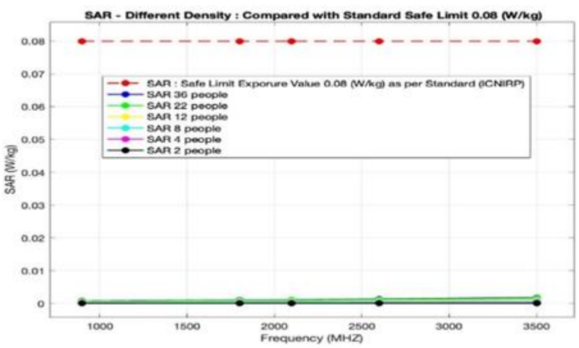


**Figure 9:** SAR values compared with standard safe limit 0.08 (W/kg) in Crowds of Varying Density (6m diameter) at 900, 1800, 2100, 2600, and 3500 MHz.

### 2.3 Impact of Increased Electrical Field Strength

This section investigates the effects of increasing the electrical field strength on a 36-person model. We focus on two key parameters: Skin Depth and SAR. Unlike previous sections, simulations were conducted only at three specific frequencies: 2100 MHz, 2600 MHz, and 3500 MHz. Skin Depth in a 36-People Crowd (6m diameter) at 2100, 2600, and 3500 MHz are similar to coherent waves with different magnitudes.


**Figure 10:** SAR values compared with standard safe limit 0.08 (W/kg) in a 36-People Crowd (6m diameter) at 2100, 2600, and 3500 MHz.

### 2.4 Effective Radiated Power (ERP)

For Constant ERP, E vs distance R is calculated using Equation 16. However, this equation requires the power density and Gain G, we employed data from the base station's parameters illustrated in Table 3 below;

Table 3 The base station’s parameters.

| Radiation parameters | Frequency band | | | | |
|---|---|---|---|---|---|
| | 900 MHz | 900 MHz | 1800 MHz | 2100 MHz | 5000 MHz |
| Pt [W] | 10.4 | 500 | 250 | 250 | 501 |
| Gmax [dB] | 15 | 15.5 | 17.8 | 18.3 | 23.0 |

ERP was presented in two plots for better visualization: 1-20 meters and 20-100 meters.

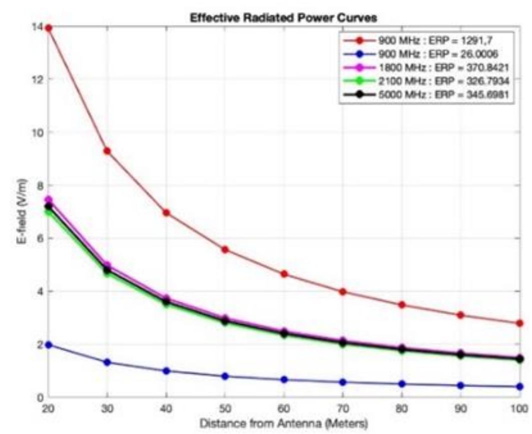


**Figure 11:** For different frequencies and Effective Radiated Power, E Curves vs. Distance (20-100 Meters)(Far Fields

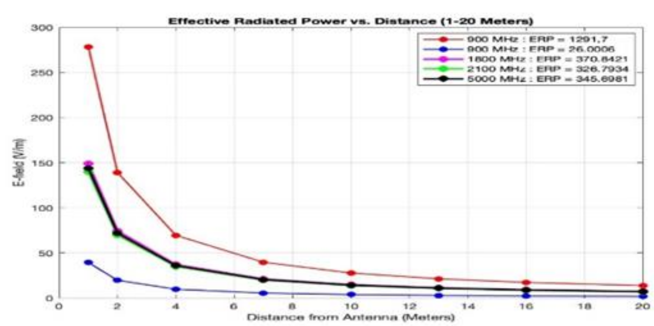


**Figure 12:** For different frequencies and Effective Radiated Power, E Curves vs. Distance (1-20 Meters)(NearFields)

## 3. Comparison of SAR Across Different Literature

Across different kinds of literature, it has been noticed that there is a lack of study for specifically SAR Whole Body. Following the completion of SAR calculations and simulations, we compared our results with existing literature[7]. Table 4 specifically focuses on this comparison for frequencies of 900 MHz and 1800 MHz.

Table 4 Comparison of SAR: Discrete Model vs Other Study.

| SAR Whole body [W/Kg] | Frequency band | | | | | |
|---|---|---|---|---|---|---|
| | 900 MHz | | | 1800 MHz | | |
| | Electrical field | | | | | |
| | 4.50 [V/m] | 4.70 [V/m] | 5.10 [V/m] | 4.60 [V/m] | 5.15 [V/m] | 6.20 [V/m] |
| SAR (AMRANI, 2020) | 0.0120 | 0.0180 | 0.0150 | 0.0170 | 0.0200 | 0.0300 |
| SAR (DiscreteModel) | 0.0156 | 0.0171 | 0.0201 | 0.0226 | 0.0283 | 0.0411 |

## 4. Discussions and Conclusions

### 4.1 Analysis of Coherent and Incoherent Fields (12-Person Model Influence)

Our simulations reveal minimal differences in behavior between coherent and incoherent electric fields, regardless of polarization (vertical/horizontal). Both experience attenuation and distortion. However, skin depth shows a frequency-dependent decrease for all scenarios (coherent/incoherent, vertical/horizontal) with a peak around 900 MHz. This decrease is minimal between field types. Furthermore, SAR exhibits a positive correlation with frequency (for both coherent and incoherent fields. Interestingly, in the coherent case, vertical polarization consistently shows higher SAR than horizontal. Conversely, incoherent fields see both polarizations initially increase but then switch roles around 2300 MHz.

### 4.2 Varying Crowd Density Effects on Electrical Field, Skin Depth, and SAR

Simulations explored how crowd density affects electric field attenuation. We varied the number of people (2 to 36) within a fixed 6-meter diameter space. While frequency (900 MHz to 3500 MHz) slightly affected the electric field itself, higher crowd density led to increased attenuation, especially at 36 people (3500 MHz field reduced to 9.903 x 10^-1 V/m). Unlike the electric field, skin depth remained constant across densities but showed a frequency-dependent decrease (peak at 900 MHz). Similarly, the SAR increased with both higher crowd density and frequency (reaching a maximum of 0.001801 W/kg for the 36-person model at 3500 MHz).

### 4.3 Impact of Increased Electrical Field Strength

Similar to previous observations, skin depth remained constant (around 2.28 x 10-2 meters at 900 MHz) regardless of increasing electric field strength (2 V/m to 10 V/m) within a 36-person model. However, skin depth did decrease with frequency (as seen before). In contrast, the SAR in the 36-person model exhibited a direct increase with higher electric field strength. Importantly, the safe exposure limit (0.08 W/kg) was only exceeded for frequencies above 3 GHz and a high field strength of 7 V/m.

### 4.4 Analysis of Effective Radiated Power (ERP)

Simulations on ERP vs distance from the antenna (R) revealed that field strength weakens with increasing distance, and for a specific frequency, ERP remains constant across distances studied (1-100 meters). We also observed that frequency matters at short distances (<20 meters). For example, at higher frequencies (e.g., 5000 MHz) reach a maximum of 7 V/m at 20 meters, while at lower frequencies (e.g., 900 MHz at 26 Watt) reach a maximum of 2 V/m at 20 meters but can reach 14 V/m at the same distance with higher ERP (1291Watt).

On the other hand, a dramatic electric field rises near the antenna (<10 meters). The field intensity increases significantly for all frequencies and ERPs. At 2 meters, 900 MHz (26 Watt) shows 20 V/m and 5000 MHz shows 72 V/m. This rise is even stronger for 900 MHz (1291 watts), reaching 139 V/m at 2 meters and 278 V/m at 1 meter.

### 4.5 Comparative Analysis: SAR values with existing literature

We compared our calculated Averaged SAR with existing literature. These studies measured SAR at specific locations near base stations at different distances.

In contrast, our study employed a discrete model method to calculate SAR, focusing on a single source of the electric field. This approach differs from the comparative studies that likely involved multiple sources in real-world environments.

Table 4 presents the comparison. As you can see, our SAR values (based on the discrete model) tend to be slightly higher. This difference might be attributed to the varying number of people considered in each scenario. For instance, the highest simulation SAR data we used represents a crowded environment with 36 people density. Conversely, the comparative studies obtained their results from laboratories or offices, which wouldn't typically have such a high density of people. Based on this analysis approach, the results are reasonable and acceptable.

In conclusion; this research successfully employed a Discrete Model to analyze the behaviour of electromagnetic waves in crowded environments with up to 36 people [11]. The study focused on four key parameters: SAR, Electrical Field, Skin Depth, and ERP. Notably, the type of electrical field (coherent or incoherent) and its polarization (vertical or horizontal) had minimal influence on the overall wave behaviour.

Skin depth, and. Crowd density directly affects SAR, a measure of energy absorbed by the body. Higher densities resulted in increased SAR values, with minimal impact on skin depth. Importantly, simulations confirmed this effect even in crowded environments.

For example, with a weak electric field (1 V/m), the maximum simulated SAR value (0.0018 W/kg) remained far below the safety limit (0.08 W/kg). However, it is crucial to note that SAR increases directly with increasing electrical field strength. While this study observed safe values at 1 V/m, a separate test with a stronger field (7 V/m) did show SAR exceeding the safety limit. This highlights the dependence of SAR on field strength. These findings offer valuable insights into how electromagnetic waves interact with crowds and establish a foundation for further research into potential health effects.


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