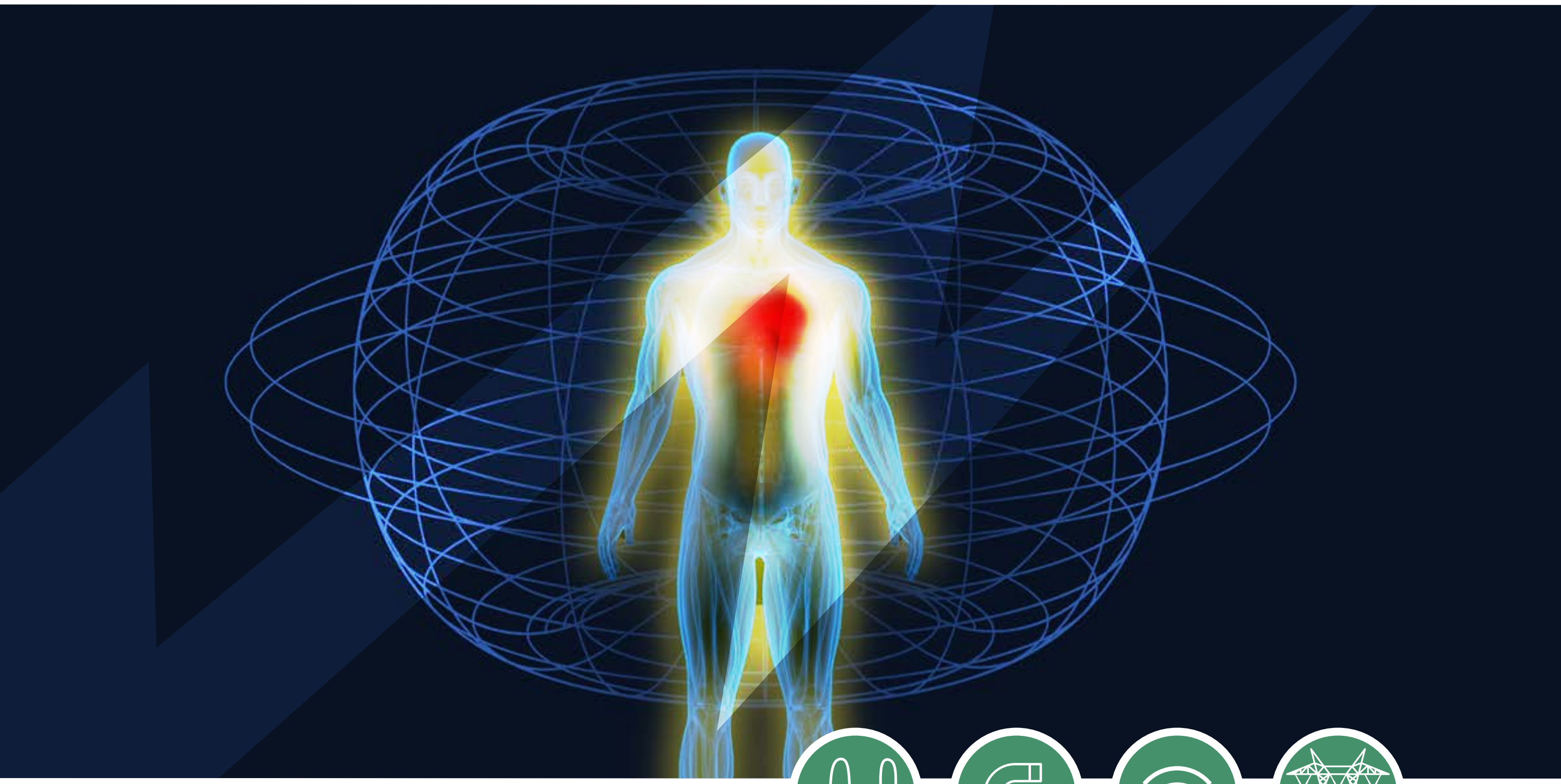
AFSEC

GUIDANCE ON
ELECTROMAGNETIC FIELD EXPOSURE



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EXECUTIVE SUMMARY

The occurrence, growth and expansion of Electromagnetic Field Exposure is taking an unprecedented growth vis-à-vis the development of the digital era. Many of the new appliances, machinery and the operation of electrical and electronic devices introduce complex electromagnetic environment that the human body is exposed to. This guide explains the existence of these hazardous electromagnetic fields and classify them as Low Frequency and High Frequency effects respectively. The guide further considered the effect of these fields on biological tissues and organs that are exposed to them. Beginning with a description of properties of tissues in constant fields, the guide describes the possible biological effects on human from the perspective of static magnetic fields, LF fields, HF radiation. A brief description of the relationship between cancer and electromagnetic fields, EMF and nerve simulation, temperature rise, fertility, reproduction, and childhood development were covered.

Additionally, the guide provides an overview of existing protection measures in line with provisions in IEC standards, the ICNIRP and ICES publications. Exposure limits for public areas and occupational areas were presented for low and high frequencies covering in line with ICNIRP, 2010 and 2020.

Furthermore, three case scenarios relating to the EMF exposure were presented to illustrate some of the palpable effects of EMF exposure. The first on presented some laboratory result of exposure due to household appliances. The second on presented EMF exposure in the vicinity of power lines and their potential effect on the surrounding environment and finally the third one dealt with measuring EMF about radio antennas installed on rooftop.

The guide is a concise summary of important information relevant to EMF exposure and protection that necessary workers in electric power, telecommunications, ICT, electronics, renewable energy sectors.

1 INTRODUCTION

Electromagnetic field exposure occurs when an individual (or any body part) comes into the influence of electric and magnetic emissions produced by voltage and electric current sources. Through this, electromagnetic energy will be transferred to the exposed body, thereby inducing biological effects. However, when this energy becomes high, it can result in adverse health issues. An adverse health effect causes detectable impairments of the health of the exposed individual or of his or her offspring; a biological effect, on the other hand, may or may not result in an adverse health effect.

This AFSEC publication provides guidelines based on international criteria for protection against established adverse health effects in humans, associated with EMF exposure. Electromagnetic field in real sense is not a new phenomenon as the creature is surrounded by various electromagnetic activities and sources of EMF, both naturally occurring and man-made.

According to the World Health Organisation (WHO), during the 20th century, environmental exposure to man-made EMFs has been steadily increasing as growing electricity demand, ever-advancing technologies and changes in social behaviour and leading to the creation of more and more artificial sources.

Everyone is exposed to a complex mix of weak electric and magnetic fields, both at home and at work, from the generation and transmission of electricity, operation of domestic appliances and industrial equipment, to telecommunications and broadcasting. Also, tiny electrical currents exist in the human body due to the chemical reaction that occur as part of the normal bodily functions, even in the absence of external electric fields. For example, nerves relay signals by transmitting electric impulses. Most biochemical reactions from digestion to brain activities go along with the re-arrangement of charged particles. Even the heart is electrically active and is traceable with the help of an electrocardiogram. Therefore, the phenomenon is not alien to the human biological systems, however, the level of exposure to the external sources needs to be controlled to ensure that no short-term nor long-term effect will arise.

Over the course of the past decade, numerous electromagnetic field sources have become the focus of health concerns, including electrified railway, high voltage power lines, microwave ovens, computer and TV screens, security devices, radars and most recently mobile phones and their base stations. Furthermore, EMFs are categorised as either ionising or non-ionising radiation types. This Guidance is for human protection from the

Figure 1: Electromagnetic fields around human body

non-ionising radiation types. References are made to the ionising radiation types, where required, for clarification. The contents of these guidelines are based on research works carried out primarily by members of the Electromagnetic Compatibility Committee, TC77 of AFSEC and also relying on report from the following organisations:

- World Health Organisation
- International Commission for Non-ionising Radiation Protection (ICNIRP)
- International Committee of Electromagnetic Safety

Note that references are made to research outputs from independent researchers as well as analysis performed by AFSEC. According to ICNIRP and ICES, the established human mechanisms fall within the category of short-term effects and such effects are understood in terms of recognised interaction mechanisms. The exposure limits defined in ICNIRP and ICES publications are therefore not based on the potential effects of long-term exposure because:

- There is no sufficient, reliable evidence to conclude that long-term exposures to electric and magnetic fields at levels found in communities or occupational environments are adverse to human health or cause a disease, including cancer.
- There is no confirmed mechanism that would provide a firm basis to predict adverse effects from low-level, long-term exposure.

Therefore, like ICNIRP and ICES, this Guidance is for preventing established short-term effects of EMFs on the body.

2 BIOLOGICAL EFFECTS OF EMF

2.1 Overview of Biological Effects of EMF

Living organism are subjected to many different forms of man-made electromagnetic fields and radiation. Besides the primary intended roles, these energies produce other effects that may influence the life activities of living organisms. The change produced depends on many biological and physical factors. They may be grossly apparent and visible soon after exposure of the living organism or they may not be apparent at all and take a while to manifest. The objective of this Guide is to provide information relating to the EMF exposure in the frequency range from Extremely Low Frequency to Microwaves. It is noted that electromagnetic fields in this frequency range have low energy photons; therefore, under ordinary circumstances, they are too low to produce ionisation or excitation. Consequently, the fields of interest are often referred to as low energy or non-ionising radiation. The absorption of electromagnetic energy is governed by the electromagnetic properties of tissue media, specifically permittivity and permeability. In addition, the depth of penetration into the tissue is a function of frequency. In general, when considering the interaction of electromagnetic fields with biological systems, it is necessary to account for the frequency or wavelength and its relationship to the physical dimension of the body.

2.2 Electromagnetic Fields

Electric and magnetic fields are part of the electromagnetic spectrum which extends from static electric and magnetic fields, through high frequency or radio frequency, infrared radiation and visible light to X and gamma-rays, as illustrated in Figure 2.

2.3 Near and Far Fields

The terms "far field" and "near field" describe the fields around an antenna or a scattering object. Generally, near field occurs in a region close to the antenna and has an extension of less than one wavelength. Meanwhile the far field is considered at regions distant from the antenna in the multiples of the wavelength.

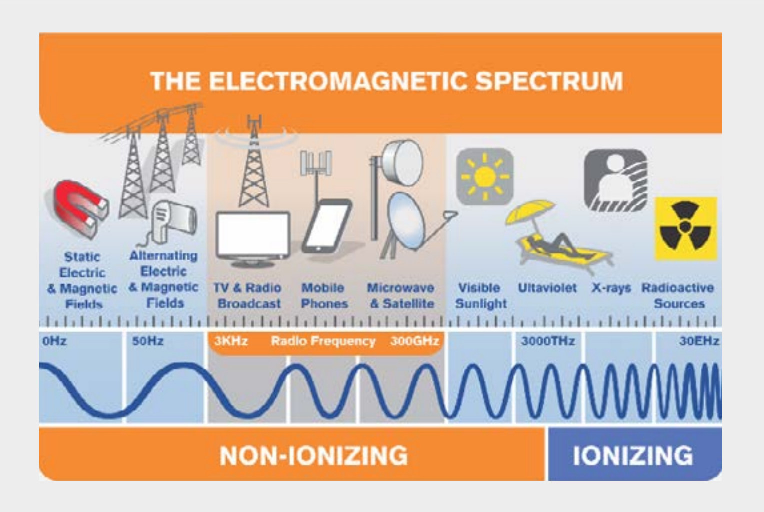


Figure 2. Electromagnetic Field Spectrum

A structure is capable of efficiently radiating electromagnetic waves only when its dimensions are significant in comparison with the wavelength, λ, defined as follows in free space:

$$\lambda = \left(\frac{c}{f}\right) \tag{1}$$

$$\lambda_{50\text{Hz}} = \frac{3 \times 10^8}{50} = 6000 \text{ km} \tag{2}$$

Thus, most available man-made structures are much smaller than one wavelength. The poor radiation efficiency of electrically small structures - structures whose largest linear dimension $L \ll \lambda$, can be illustrated easily for line antenna.

For a radiating antenna, shown in Figure 3, the ratio of the voltage to current at its terminals, for the antenna with no load attached, defines its impedance as follows:

$$Z_A = R_A + jX_A \tag{3}$$

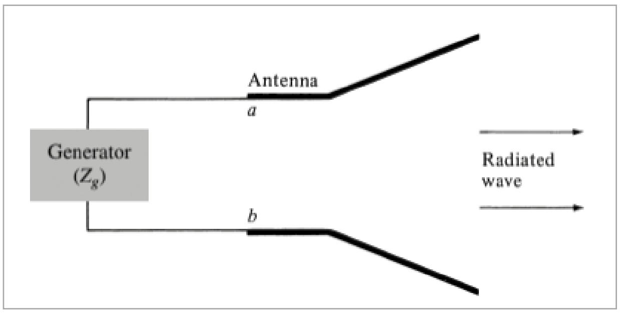


Figure 3: Antenna in transmission mode

Where:

- $\boldsymbol{Z_A}$= antenna impedance at terminals ***a –b***
- $\boldsymbol{R_A}$= antenna resistance at terminals ***a –b***
- $\boldsymbol{X_A}$= antenna reactance at terminals ***a –b***

In general, the resistive part of equation (3) consists of two components; that is:

$$R_A = R_r + R_L \tag{4}$$

Where:

- R_r = radiation resistance of the antenna
- R_L = loss resistance of the antenna

The antenna radiates its real power through the radiation resistance R_r .

For an infinitesimal dipole antenna (usually $\boldsymbol{l \leq \lambda/50}$), the radiation resistance R_r of a current element is given by:

$$R_r = 80\pi^2 \left(\frac{l}{\lambda}\right)^2 \tag{5}$$

While for a small dipole its radiated power is one-fourth (¼) of that obtained for the infinitesimal dipole. Thus, the radiation resistance reduces to

$$R_r = 20\pi^2 \left(\frac{l}{\lambda}\right)^2 \tag{6}$$

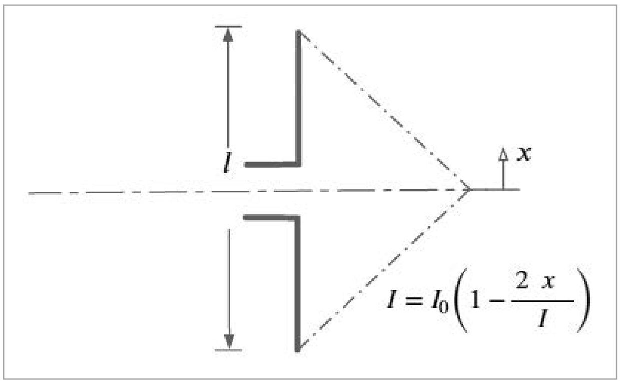


Figure 4: Centrefed antenna.

- Radiated Power $\mathrm{P_r} = \mathrm{I^2R_r}$, I being the current flowing through the antenna
- dissipated Power as heat in the antenna wires, $\mathrm{I^2R_L}$ since $\mathrm{R_r}$ is much larger than $\mathrm{R_r}$.
- Any object subjected to low frequency electric and magnetic fields usually does experience effects of radiation.
- Any configuration that carries current, sets up electric and magnetic fields components which store energy without contributing to radiation. A sort of linear antenna in free space generates in addition to the radiation field $\mathrm{E_r}$ when subject to an alternating current:
  - an electrostatic field, $\mathrm{E_s}$ and
  - an induction field, $\mathrm{E_i}$

Note that $\mathrm{E_i}$ and $\mathrm{E_i}$ do not contribute to the radiated power.

- $\mathrm{E_r}$ is proportional to $\frac{1}{r}$; $\mathrm{E_s}$ is proportional to $\frac{1}{r^2}$; and $\mathrm{E_i}$ is proportional to $\frac{1}{r^3}$.
- At distances $r = \frac{\lambda}{2\pi}$, $\mathrm{E_i} = \mathrm{E_r}$

Thus, objects at distances of a few kilometres from a system are exposed to non-radiating field components. This component is an order of magnitude larger than the part that contributes to radiation.

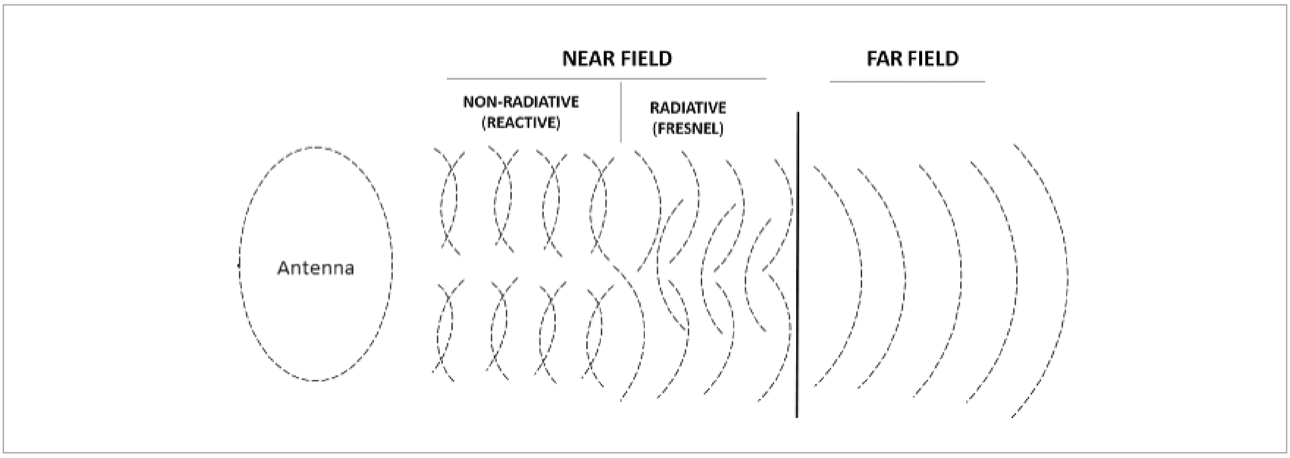


Figure 5. Near field vs far field

2.4 Field Regions

The space surrounding an antenna is usually subdivided into three regions: (a) reactive near-field, (b) radiating near-field (Fresnel) and (c) far-field (Fraunhofer) regions as shown in Figure 6.

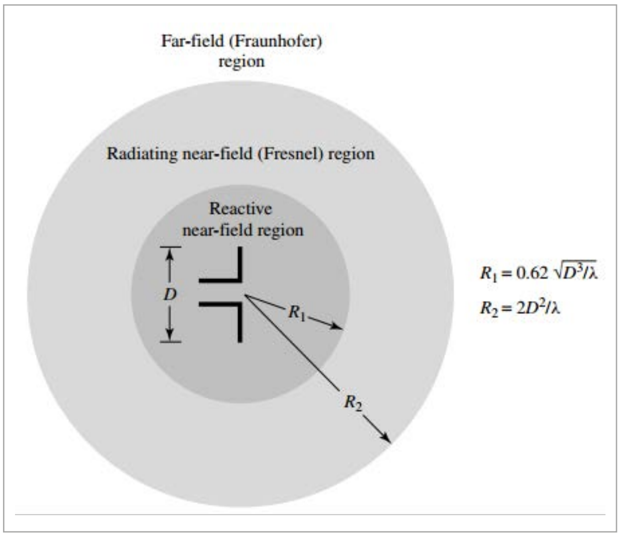


Figure 6: Field regions of an antenna

2.4.1 Reactive Near-Field Region

Reactive Near-FieldRegion is defined as “that portion of the near-field region immediately surrounding the antenna wherein the reactive field predominates.” For most antennas, the outer boundary of this region is commonly taken to exist at a distance

$$R < 0.62\sqrt{\frac{D^3}{\lambda}}$$

from the antenna surface, where λ is the wavelength and D is the largest dimension of the antenna.

The wave number k is defined by:

$$k = \frac{2\pi}{\lambda} \tag{7}$$

The ratio of electric to magnetic fields is equal to

$$Z_w = \frac{E}{H} \simeq \eta \tag{8}$$

Where:

- E is the electric field intensity
- H is the magnetic field intensity
- Z_W = wave impedance
- η = intrinsic impedance
  ($377\Omega = 120\pi$ ohms for free space)

In conditions where $\mathrm{k.r} \ll 1$ the electromagnetic field components can be approximated by equation 9 below:

$$\left.\begin{aligned}
E_r &\simeq -j\eta\frac{I_0 l e^{-jkr}}{2\pi k r^3}\cos\theta\\
E_\theta &\simeq -j\eta\frac{I_0 l e^{-jkr}}{4\pi k r^3}\sin\theta\\
E_\phi &= H_r = H_\theta = 0\\
H_\phi &\simeq \frac{I_0 l e^{-jkr}}{4\pi r^2}\sin\theta
\end{aligned}\right\}\quad kr \ll 1 \tag{9}$$

Where r is the distance from the antenna to the point of observation

2.4.2 Radiating Near-Field (Fresnel) Region

It is defined as "that region of the field of an antenna between the reactive near-field region and the far-field region wherein radiation fields predominate and wherein the angular field distribution is dependent upon the distance from the antenna. If the antenna has a maximum dimension that is not large compared to the wavelength, this region may not exist. For an antenna focused at infinity, the radiating near-field region is sometimes referred to as the Fresnel region on the basis of analogy to optical terminology. If the antenna has a maximum overall dimension which is very small compared to the wavelength, this field region may not exist." The inner boundary is taken to be the distance

$$R \geq 0.62\sqrt{\frac{D^3}{\lambda}}$$

and the outer boundary the distance $R < \frac{2D^2}{\lambda}$

where D is the largest dimension of the antenna. In this region the field pattern is, in general, a function of the radial distance and the radial field component may be appreciable.

In conditions where $(\mathrm{kr} > 1)$ the electromagnetic field components can be approximated by equation 10 as follows:

$$\left.\begin{aligned}
E_r &\simeq \eta\frac{I_0 l e^{-jkr}}{2\pi r^2}\cos\theta\\
E_\theta &\simeq j\eta\frac{k I_0 l e^{-jkr}}{4\pi r}\sin\theta\\
E_\phi &= H_r = H_\theta = 0\\
H_\phi &\simeq j\frac{k I_0 l e^{-jkr}}{4\pi r}\sin\theta
\end{aligned}\right\}\quad kr > 1 \tag{10}$$

2.4.3 Far-field (Fraunhofer) Region

It is defined as "that region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. If the antenna has a maximum overall dimension D, the far-field region is commonly taken to exist at distances greater than $\frac{2D^2}{\lambda}$ from the antenna, λ, being the wavelength.

In conditions where $(\mathrm{k.r} \gg 1)$ the electromagnetic field components can be approximated by equation 11 as follows:

$$\left.\begin{aligned}
E_\theta &\simeq j\eta\frac{k I_0 l e^{-jkr}}{4\pi r}\sin\theta\\
E_r &\simeq E_\phi = H_r = H_\theta = 0\\
H_\phi &\simeq j\frac{k I_0 l e^{-jkr}}{4\pi r}\sin\theta
\end{aligned}\right\}\quad kr \gg 1 \tag{11}$$

Figure 7 shows the ratio $\mathbf{E}$ to $\mathbf{H}$ for $\theta = 90^0$.

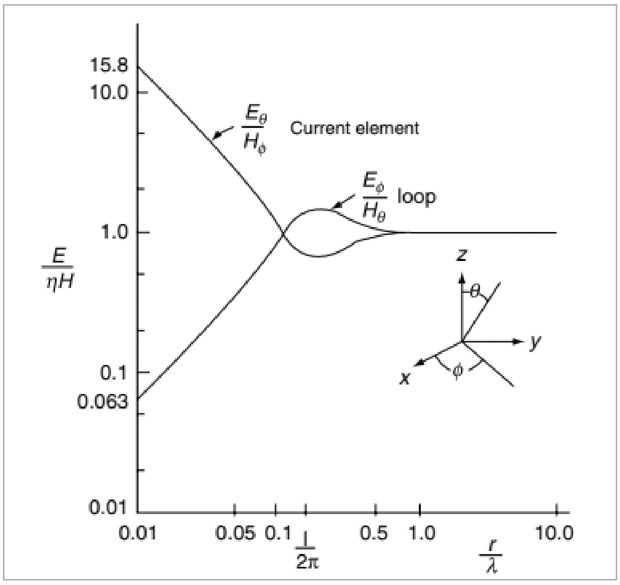


Figure 7: The ratio of the $\mathbf{E}$ to $\mathbf{H}$ field at $\theta = 90^0$

The amplitude pattern of an antenna, as the observation distance is varied from the reactive near field to the far field, changes in shape because of variations of the fields' magnitude and phase. A typical progression of the shape of an antenna, with the largest dimension D, is shown in Figure 8. It is apparent that in the reactive nearfield region the pattern is more spread out and nearly uniform, with slight variations.

As the observation is moved to the radiating near-field region (Fresnel), the pattern begins to smooth and form lobes. In the far-field region (Fraunhofer), the pattern is well formed, usually consisting of few minor lobes and one, or more, major lobes.

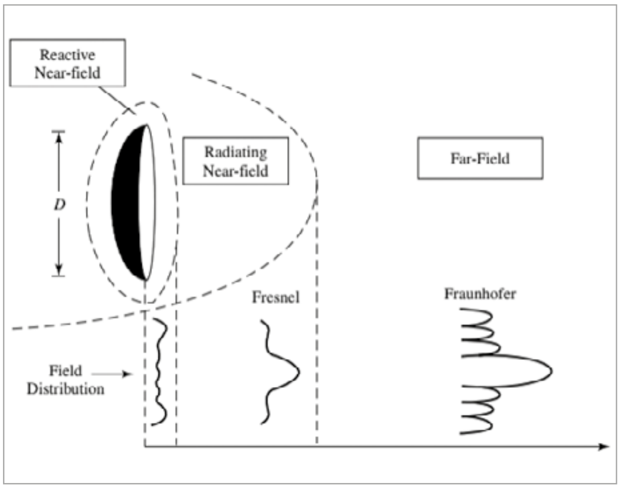


Figure 8: Typical changes of antenna amplitude pattern shape from reactive near field towards far field. [1]

A living organism exposed to a static field or to a non-radiating near field may extract energy from it, however the coupling mechanism is very different than at high frequencies, where energy is transferred by radiation.

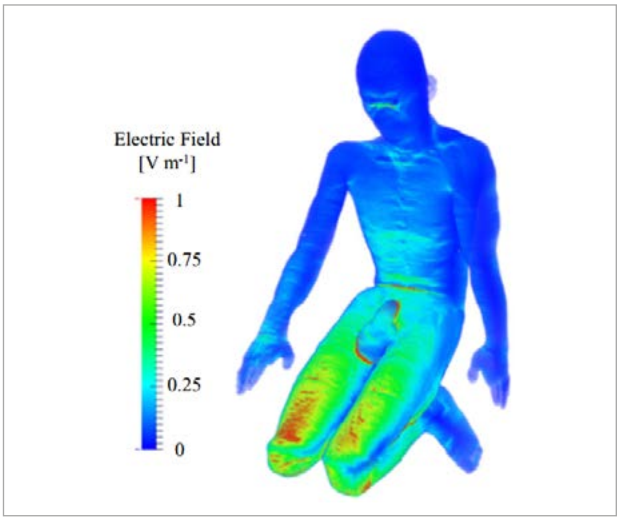


Figure 9: A living organism exposed to an Electric Field, modelled in crouching position.

In the near field, the relative magnitude of the electric and magnetic fields is a function of the current or charge configuration and the distance from the electric system.

In the radiation field (far field) the ratio of the electric and magnetic field is fixed. Systems carrying DC or low frequency current, will only under very exceptional circumstances be large enough to produce heating effects inside a living object. Note, non-thermal effects are possible, thus an electric field of sufficient magnitude may orient dipoles or translate ions or polarise neutral particles.

2.5 Temperature Rise

Radiated power can generate heat in the body. There is a dearth of radiofrequency exposure research using sufficient power to cause heat-induced health effects. Therefore, it is important to keep this induced heat to a safe level.

2.6 Low Frequency Fields

Low frequencies belong to the band 1Hz to 100 KHz and therefore cover a wide range of applications. The main sources of Low Frequency (LF) Fields are High Voltage transmission lines and all devices containing current-carrying wire, including equipment and appliances in industry and at home operating at power frequencies of 50 Hz in most countries.

The LF field created by High Voltage transmission lines can be described using general Maxwell equations. This LF can be characterized by quasi-stationary specific features.

Quasi-stationariness of the field is due to its low frequency. Each compound of LF can be therefore calculated separately. Calculation is simplified using simple electrostatics for the determination of intensity of electric field and magnetostatics for calculation of magnetic flux density. Voltage and current sources of these fields are in phasor representation.

2.6.1 LF Electric field

Calculation of LF Electric field E, begins with Coulomb law, in its integral form Equation 11

$$\mathbf{E}(\mathrm{p}) = \frac{1}{4\pi\varepsilon_0}\int_{l}\frac{\tau \mathrm{d}l}{\mathrm{r}^3}\mathbf{r} \qquad (11)$$

τ is the linear charge on conductor; p is any desired point of calculation in space of E; vector $\mathbf{r}$ is directed from element of conductor dl to p; ε_0 is the permittivity of free space.

The characteristics of these fields depend on the line voltage, and on the geometrical dimensions and positions of the conductors of the transmission line. To avoid the effects of vegetation or irregularities on the terrain, the unperturbed field strength is usually computed or measured at a given height above ground level.

2.6.2 LF Magnetic Flux Density, B

Calculation of B, is much simpler than E due to overall character of the magnetic flux density. The sources of B are currents only, so the ground has basically no influence on it. The general equation is obtained, from the Biot–Savart law, which can be derived from Maxwell equations with a quasi-static assumption, as follows:

$$\mathbf{B}(\mathrm{p}) = \frac{\mu_0}{4\pi}\int_{l}\frac{\mathrm{I}\mathrm{d}\mathbf{l}\Lambda\mathbf{r}}{|\mathbf{r}^3|} \qquad (12)$$

Where I, is the current flowing in the conductor, vector $\mathbf{r}$ is directed from conductor $\mathrm{d}l$ to the point of observation; μ_0 is the permeability of free space.

2.7 Mechanism of Interactions: Permittivity and Permeability

The electromagnetic properties of biological materials are characterised by the electrical permittivity and magnetic permeability. Biological tissues have permeability values close to that of free space and independent of frequency. However, biological tissues are not free of ferromagnetic materials.

The permittivity of biological materials displays characteristics dependent on frequency. Typically, dielectric constant decreases while conductivity increases with increasing frequency. Biological materials exhibit very high dielectric constant especially at low frequencies, compared to many other homogeneous solids and liquids. Biological tissues are composed of macromolecules, cells, and other membranes bound substances.

1. Mobile counter ions associated with fixed charges on cell membranes and membranes capacitances dominate the behaviour of the dielectric constant at low frequencies.

2. The frequency dependent results from the drastic change in membrane capacitance as frequency increases at extremely low frequencies.

3. An applied electric field causes charges to accumulate at boundaries, separating tissues regions of different dielectric properties – say intra - and extracellular space.

4. As the frequency increases, insufficient time is allowed during each cycle to permit complete charging to the cell membranes. The total charges per cycle must decreases, along with the membrane capacitance, as the frequency increases.

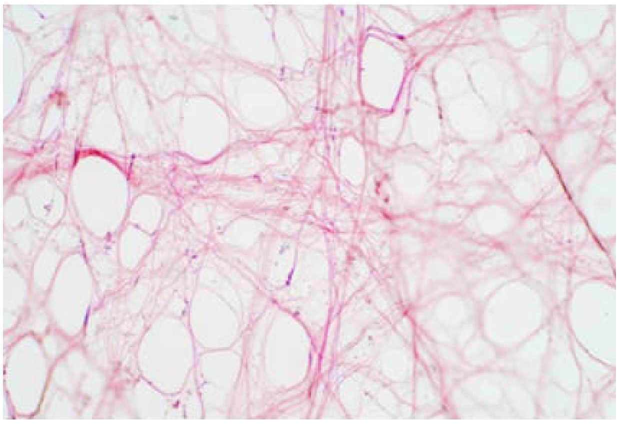


Figure 10: Areolar connective tissue under the microscope view

The electric properties of the tissues of living organisms can be divided into three groups according to their water content:

- Suspensions of cells and protein molecules of liquid consistency (blood, lymph),

- Similar suspensions in a condensed state (muscle, skin, liver, etc.), and

- Tissues with a low water content (fat, bone). Cells, colloidal particles, protein molecules, and other micro-particles acquire a dipole moment when they are suspended in an electrolyte solution.

Electric charges in tissues are also represented by the dipole molecules of water and, finally, by the electrolyte ions.

2.8 Coupling Mechanism

A biological effect is an established effect caused by, or in response to, exposure to a biological, chemical, or physical agent, including electromagnetic energy. A biological effect occurs when exposure to electromagnetic field cause any noticeable or detectable physiological response in a biological body, such as alterations of the structure, metabolism, or functions of a whole organism, its organs, tissues, and cells [1,2]. These changes are not necessarily harmful to individuals and may also have beneficial consequences for a person's health or well-being.

The human body has a sophisticated mechanisms to adjust to various influences it encounters in its surroundings. However, it does not possess adequate compensation mechanisms for all biological effects. If some biological effects are outside the range for the human body to compensate, it can result in adverse health effects. For example, if the human system is stressed for extended periods of time and the induced changes are irreversible, these conditions may be considered as a health hazard.

Therefore, biological effect may or may not result in an adverse health effect, while an adverse health effect results in detectable health impairment of the exposed individual.

Adverse health effects are often the result of accumulated biological effects over time and depend on intensity and frequency of exposure. It is an established fact that electromagnetic fields above certain levels can induce biological effects. Experiments with healthy subjects suggest that short-term exposure at the levels present in the environment do not result in any apparent detrimental effects. On the other hand, the high-level exposure that might be harmful is restricted by national and international guidelines.

So far, there is currently no well-established scientific evidence to conclude that low level long-term exposures to electromagnetic fields at levels found in the environment are adverse to human health, and also there is no confirmed mechanism that could provide a firm basis to predict these adverse effects [3].

A fundamental and detailed knowledge of the biological effects is required to completely understand the potential health risk. The understanding of interaction mechanisms could be used to identify the appropriate dosimetry, to predict dose–response relationships, to design better experiments, and to determine if detrimental effects are expected at particular exposure levels [4].

It is important to emphasise that the coupling between electromagnetic field and the biological body varies significantly with frequency.

3 PROPERTIES OF TISSUES IN CONSTANT FIELDS

3.1 Overview

Biological tissues in a constant electric field are polarised to some extent - the charged particles move along the lines of force and the dipole molecules are oriented in the same direction. If a constant voltage is applied directly to tissue, an electric current will be produced in it, due to ionic conduction.

Each cell is surrounded by a wall with a surface capacitance of 0.1-3 μF/cm and a surface resistance of 25 to 10,000 Ω/cm^2. The intercellular and intracellular media have a resistance of the order of 100-300 Ω/cm^2 and a dielectric constant of about 80. It should be noted that on application of a constant voltage, the cell wall will act as an insulator and current will flow only in the extracellular medium. A constant voltage can also give rise to the phenomenon of electrophoresis - the migration of electrically charged particles (cells, macromolecules) [5].

3.2 Static Electric Fields

The static electric fields do not penetrate the human body because of its high conductivity. The electric field can induce an electric charge on the body surface, which can be sometimes perceived via its interaction with body hair and also as spark discharges. However, apart from this superficial sensory stimulation of hair and skin as the basis for perception of the field, the limited number of animal and human laboratory studies, which have investigated the effects of exposure to static electric fields, have not provided evidence of adverse health effects.

3.3 Static Magnetic Fields

People are generally unaffected by static magnetic fields, unless they move around these fields. The magnetic field will thus exert a physical force on electrically charged particles moving through the field. Therefore, movement with respect to magnetic field can induce the electric fields in tissues and these can affect the nervous tissues. The magnitude of the induced electric fields will depend on the total change of the magnetic field.

There are three established physical mechanisms by which static magnetic fields can influence biological systems: magnetic induction, magneto-mechanical interaction, and electron spin interactions [6].

Magnetic induction arises through the following types of interaction: electrodynamic interactions with moving electrolytes where the static field exerting Lorentz force on a moving ionic charge carriers and cells in the blood will result in the induced electric fields and currents; induced electric fields and currents may also be induced by movement in a static magnetic field, where motion along a field gradient or rotational motion, either in a uniform field or in a field gradient, will result in the change of magnetic flux thereby inducing an electric current.

The magneto-mechanical interactions between static magnetic field and biological bodies are realised by magneto-orientation or magneto-translation, where the former is related to paramagnetic molecules experiencing a torque in a static field orienting them in a way that minimises their free energy within the field, while the latter is due to a net translational force on both diamagnetic and paramagnetic materials in the presence of field gradients.

The last mechanism is via complex electronic interactions that may affect the rate of specific chemical reactions. These electron spin interactions are related to certain metabolic reactions involving transitional state comprising a radical pair where an applied magnetic field affects the rate and the extent to which the radical pair converts to a state in which recombination is no longer possible.

3.4 Time Varying Fields

There are three established basic coupling mechanisms through which time-varying electromagnetic fields interact with the biological body [7]:

- Coupling to LF electric fields;
- Coupling to LF magnetic fields;
- Energy absorption from electromagnetic radiation

These coupling mechanisms depend on the field characteristics such as frequency, spatial uniformity, propagation and polarisation direction, etc., but also on the human body characteristics such as size, morphology, and posture.

Figure 10 illustrates the coupling mechanism of the human body exposed to a low frequency electric and magnetic field, respectively.

3.5 Low Frequency Fields

LF fields in tissue have a long wavelength as a result of which these fields behave as though they are composed of independent, quasistatic electric and magnetic field components.

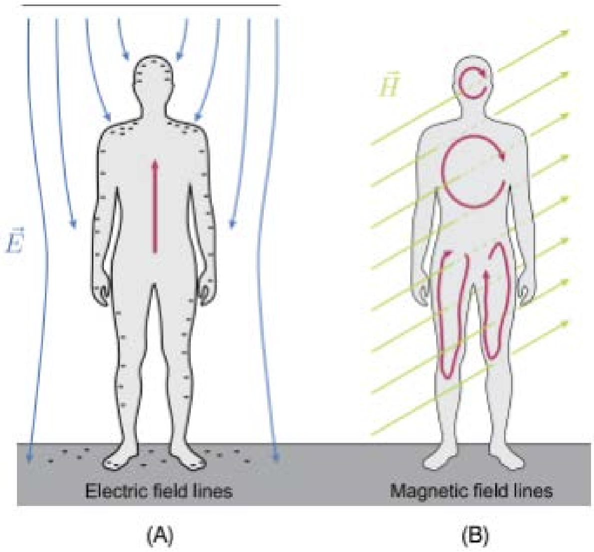


Figure 11: Human body coupling with: (A) low frequency E-Field, and (B) low frequency H- Field

Consequently, the radiating properties of LF fields can be neglected in their interactions with biological tissues. It is equally important to note that LF fields have extremely low energies and thus are incapable of disrupting chemical bonds. Furthermore, LF fields applied to biological tissue through air is the non-thermal nature of their interaction. The highest fields in tissues that can be induced by an ELF applied through air is 1 V/m, which leads to a specific energy absorption rate of 10^{-4} W/kg. This rate of energy disposition is four orders of magnitude less than the body's basal metabolic rate and produces a negligible rate of temperature rise [6].

It was previously explained that the characteristics of EM fields and their interactions with objects vary considerably with the ratio of the wavelength of the EM fields to the object size. For objects about the size of people, the wavelength will be large in comparison to the object size at frequencies below 1 MHz. Many naturally occurring electric and magnetic effects are seen in this low-frequency range. Lightning and other static discharges are examples of capacitive discharge that can source very large amounts of current over a very small area and time, thus potentially doing significant damage or inflicting pain in that small area. This same effect can be used in a smaller-scale, more controlled fashion in electrophysiology, which uses pulsed fields to heal bone or soft tissue, stimulates damaged nerves or muscles, and reduces pain. The nervous system is made up of a massive network of neurotransmitters and receptors.

By interfacing with this natural electrical system using electrodes, one can receive neural signals for analysis or stimulate nerves to produce biomechanical function. Electromyography, electrocardiograms, cardiac defibrillation or pacing, and direct nerve stimulation are a few of the applications commonly seen in this frequency band.

Most applications in the low-frequency band are for either stimulation or reception of nerves and tissues, rather than imaging. This is because low-frequency fields cannot be easily focused to provide good images. An exception to this is impedance imaging. The low and high-water-content tissues of the body have very different electrical properties (i.e., insulators as opposed to conductors), and this is used to provide local images of the body. Some simple commercial devices such as electrical scales that measure weight and estimate body mass index use this concept. Finally, since the power grid relies on low frequency (50 or 60 Hz) fields, much research is being conducted to determine if these fields, which are now so pervasive in our environment, are safe or hazardous in small doses.

3.5.1 Low Frequency Field - Electric Fields

The human body significantly perturbs the spatial distribution of a low frequency electric field [8]. Moreover, the electric field induced inside the body will be considerably smaller compared to the external electric field. As the human body is a good conductor at low frequencies, electric field lines, external to the body will be nearly perpendicular to the body surface, as shown by Figure 10A. The interaction of LF electric fields with humans results in electric current, formation of electrical dipoles, and the reorientation of the already presented electric dipoles in tissue [7]. The intensity of these effects depends on the tissue and on the frequency of the applied field. External electric fields induce a shift of surface charges on the body resulting in induced currents in the body, the distribution of which varies with the size and shape of the body.

3.5.2 Low Frequency Field - Magnetic Fields

Contrary to electric field, the human body does not significantly perturb the spatial distribution of a low frequency magnetic field. As the permeability of body tissues is similar to that of air, the internal field is similar to the external field [6].

The interaction of LF magnetic field with the human body results in induced electric fields and currents flowing in circular loops inside the body [7], as shown by Figure 10B. The magnitudes of the induced field and the current density are proportional to the loop radius, the tissue conductivity, and the rate of change and magnitude of the magnetic flux density. For a specified magnitude and frequency of magnetic field, the strongest electric fields are induced where the loop of greatest dimensions are formed. The path and the magnitude of the current induced in any part of the body depend on the tissue conductivity.

3.6 Energy Absorption from Electromagnetic Radiation

Compared to exposures to LF electric and magnetic fields resulting in negligible energy absorption and thus no measurable temperature rises in the human body, the exposure to high frequency electromagnetic radiation above around 100 kHz can result in a significant absorption of energy. The absorbed energy excites the polarised particles in the tissue sufficiently to transform them into thermal energy resulting in consequent temperature rise. The electromagnetic energy absorbed by the human body is expressed in terms of specific absorption rate (SAR).

Generally, exposure to a plane-wave electromagnetic field can result in a highly nonuniform deposition and distribution of the energy within the body, which must be assessed by dosimetric calculation and measurement procedures. The energy absorption by the human body can be approximately divided into four frequency ranges [7]:

1. 100kHz–20MHz, at which absorption in the trunk decreases rapidly with decreasing frequency, and significant absorption may occur in the neck and legs;

2. 20MHz–300MHz, at which relatively high absorption can occur in the whole body, and to even higher values if partial body (e.g., head) resonances are considered.

3. 300MHz – several gigahertz, at which significant local, nonuniform absorption occurs;

4. >10 GHz, at which energy absorption occurs primarily at the body surface.

The amount of energy absorbed will depend on numerous factors including the dimensions, morphology, and posture of the exposed body. If the human body is not grounded, its resonant absorption frequency will be around 70 MHz. For taller individuals, the resonant frequency is somewhat lower, while for shorter adults, children, babies, and seated persons, it is around 100 MHz. For grounded persons, resonant frequencies are lower by a factor of about 2. The near-field exposures can lead to a high local SAR in the head, wrists, and ankles. The local SAR and whole-body SAR strongly depend on the separation distance between the radiation source and the body.

At frequencies above approximately 10 GHz, the depth of the field penetration into tissues is small, and the SAR is not a convenient measure for determining the energy absorption in the body, therefore, a more appropriate dosimetric quantity is the incident power density of the field.

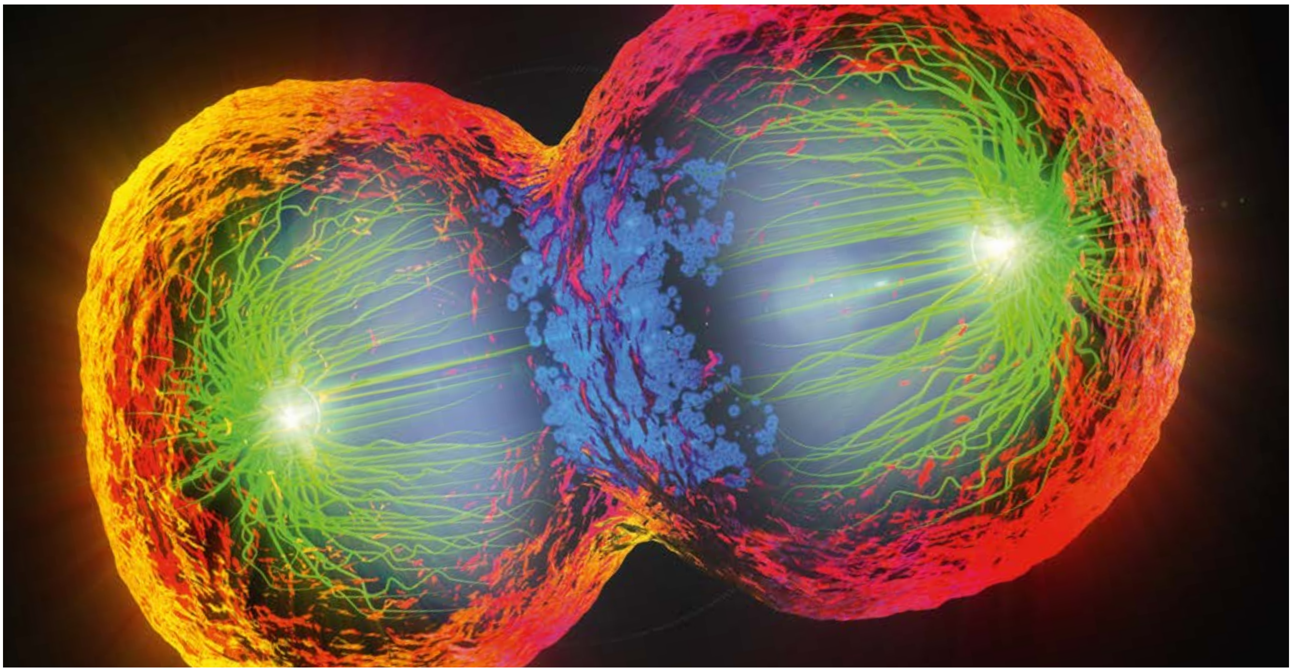
3.7 Indirect Coupling

There are two established indirect coupling mechanisms [7]. The first is the contact current resulting when the human body that comes into contact with an object at a different electric potential. The magnitude and spatial distribution of contact currents will depend on the frequency, size of the object and person, area of contact, and grounding conditions (i.e., when either the body or the object is charged by an EMF). The moment when contact is made between a person and a conducting object or even in case when an individual and a conducting object exposed to a strong field come into close proximity, the transient spark discharge occurs, also known as microshock. The other mechanism is related to the coupling of electromagnetic fields to medical devices worn by or implanted in an individual as illustrated in the AFSEC guide: EMC in Medical Devices developed by AFSEC TC 77 [50].

4 BIOLOGICAL EFFECTS

4.1 Overview of Biological Effects

The biological body response due to electromagnetic field (EMF) exposure depends primarily on the frequency of the applied field.



All relevant reported biological effects caused by EMF exposure can be classified as either non-thermal or thermal. The low frequency fields up to 5–10 MHz induce non-thermal effects such as stimulation of muscles, nerves and sensory organs, while high frequency fields in the frequency range from 100 kHz to 300 GHz result in the thermal effects. In the transition region between 100 kHz and 5–10 MHz both non-thermal and thermal effects can be produced.

The interaction of electromagnetic fields with living systems can be approximately divided into four frequency ranges, as shown on Figure 12, the static fields for frequency below 1 Hz, low frequency fields for frequencies between 1 Hz–100 kHz, intermediate frequency fields for frequencies between 100 kHz–10 MHz and high frequency fields for frequencies above 10 MHz (reference to be added).

Although the same biological effect will be induced above a few GHz, compared to lower frequencies, the heating will be restricted to the surface of the body.

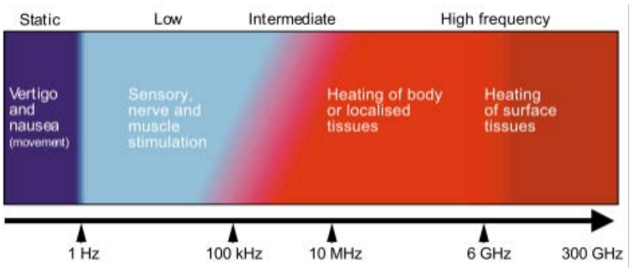


Figure 12: the biological effects from static to 300 GHz

The biological response at any given frequency depends on the intensity of the field, where low level exposure will result mainly in perceptual or sensory effects, while higher level exposure to fields will produce health effects considered to be more serious. Table 1 presents a summary of the sensory and health effects.

Table 1: Sensory and health effects per frequency range

Frequency	Sensory Effect	Health Effects
Static Magnetic Fields	Vertigo, Nausea, Metallic Taste	Altered blood flow in limbs, altered brain function; altered heart function
1 H2-10 MHz	Phosphenes (perceived as light flashes); Minor-change in brain function (1-400 Hz)	Tingling sensation of pain (nerve stimulation) muscle twitches, disturbed heart rhythm
100 kHz-6 GHz	Microwave hearing effect (200 MHz-6.5 GHz)	Excessive whole-body or localized heating or burns
6-300 GHz		Localized heat damage to eyes and skin
Note:	The effects at intermediate frequency fields (100 kHz-10 MHz) are a combination of the effect of LF and HF fields.	

4.2 Biological Effects of Static Magnetic Fields

The people at rest are generally unaffected by static magnetic fields, except at very high intensities when effects on the heart or brain functions may occur. However, movement around static magnetic field may elicit biological effects due to induced electric field affecting the nervous tissues. Some recent studies suggest that these effects may also occur whilst stationary. The magnitude of the induced electric fields depends mainly on the temporal and spatial gradients.

Particularly sensitive are the organs of balance in the ear since walking inside or even quickly moving the head in the static magnetic field might lead to feelings of dizziness or vertigo. The symptoms of nausea and other effects such as sensations of taste being produced have also been reported in the vicinity of operating MRI machines. However, all these effects are temporary, ceasing when movement around strong static magnetic field stops or even slows down. There is no evidence of permanent impairment or severe adverse effect caused by the exposure. Usually, limiting the external magnetic flux density to 2 Tesla or moving slowly inside strong static field might prevent these effects from happening.

4.3 Biological Effects of LF Fields

Low frequency magnetic field induces an electric field in the human body, which then results in stimulation of sense organs at lower field values, or stimulation of nerves and muscles (particularly in the limbs) in stronger fields. The effects on sensory organs are not harmful but could be annoying or distracting, whereas the effects in stronger fields could be unpleasant or even painful. Different tissues exhibit peak sensitivity at different frequencies, as given in Table 2.

Table 2: Sites of interaction and peak sensitivities for different effects

Effect	Site interaction	Peak Sensitivity
Metallic taste	Receptors in tongue	< 1 Hz
Vertigo, nausea	Inner ear (vestibular system)	< 0.1-2 Hz
Nerve and muscle stimulation	Blood flow-induced electric fields in tissues	
Phosphenes	Retinal cells in eye	~ 20 Hz
Tactile and pain sensation	Peripheral nerves	~ 50 Hz
Induced muscle contraction	Peripheral nerves and muscles	
Effects on heart	Heart	

The eyes are rather sensitive to the effects of induced electric fields, and the most robustly established effect of exposure is the induction of magnetic phosphenes in the retina, the perception of faint flickering light in the periphery of the visual field. The retina is part of the central nervous system (CNS) and is regarded as an appropriate model for induced electric field effects on CNS neuronal circuitry in general [8].

Exposure to low-frequency electric fields causes well defined biological responses, ranging from perception to annoyance, through surface electric charge effects. Low frequency electric fields can induce electric fields within the body tissues, that can, in principle, produce similar effects to the fields induced by exposure to low frequency magnetic fields. However, as a consequence of the body shielding effect due to its high conductivity, the induced electric field is usually of a too small magnitude to elicit adverse effects for a typical external electric field encountered in the environment.

Furthermore, low frequency electric fields produce another effect compared to magnetic fields. A person can experience a prickling or tingling sensation on the skin when standing inside very high intensity electric field such as underneath a high voltage power line on a dry day. This occurs as the low frequency electric field causes the charges to accumulate on the surface of the body, and this electrical charge causes the hairs in the skin to move and vibrate.

4.4 Biological Effects of HF Radiation

Exposure of humans to electromagnetic fields with frequencies above 100 kHz results in body heating through the absorption of energy. Depending on the exposure scenario, this can result either in heating of the whole body, or localised heating of body part, such as limbs or head. Healthy individuals usually regulate very efficiently the overall temperature of their bodies, thanks to thermoregulatory capacity of the human body. This protective mechanism is responsible for maintaining a temperature within normal range. However, if the total power absorbed by the body is large enough to cause this protective mechanism for heat control to break down, the uncontrolled rise in the body temperature (hyperthermia) occurs, leading to thermally harmful effects. The most adverse health effects due to HF exposure between 1 MHz and 10 GHz are associated with responses to induced heating, which results in a temperature rise in the tissue higher than 1°C. The prolonged temperature rise of a few degrees or more can be very dangerous.

The human body generates heat from metabolism. The basal metabolic rate (BMR) is defined as the heat production of a human in a thermoneutral environment at mental and physical rest more than 12 hr after the last meal. The standard basal metabolic rate for a 70 kg man is approximately 1.2 W/kg, but it can be altered by changes in active body mass, diets, and endocrine levels.

When humans are exposed to heating from an external thermal source at a much higher rate, thermal damage can occur. However, exposure levels comparable to the BMR might produce thermal effects due to the induction of thermoregulation. Thermal effects imposed on the body by a given specific absorption rate are strongly affected by the ambient temperature, relative humidity, and airflow. The human body regulates temperature increase due to the thermal effect through perspiration and heat exchange via blood circulation.

Certain areas with limited blood circulatory ability, such as the lens of the eye and the testes, run a particularly high risk of being damaged. The developing foetus is also known to be particularly sensitive to the effects of hyperthermia in the mother. Other thermal effects may arise around electrically conducting objects, either implanted (nails, screws, artificial hip joints, etc.) or external (watches, bows of spectacles, etc.).

For adverse health effects, such as eye cataracts and skin burns, to occur from exposure to high frequency fields, power densities above 1000 W/m^2, existing in close proximity to powerful transmitters such as radars, are needed. Furthermore, during some exposures a nonuniform distribution of absorbed radio frequency (RF) power is possible, resulting in nonuniform heating. The points in the body absorbing this power are usually referred to as the hot spot. Localised temperatures above 41.6 °C may cause protein denaturation and coagulation, increased permeability of cell membranes, or the release of toxins in the immediate vicinity where the hot spots exist.

At 6 GHz and above, the electromagnetic fields do not significantly penetrate the body and the resultant heating is largely confined to the surface tissues and skin.

Pulsed radio-frequency fields can give rise to sensory perception in the form of microwave hearing. The individuals with normal hearing can perceive pulse modulated fields with frequencies between 200 MHz and 6.5 GHz. Usually, this effect is described as a buzzing, clicking or popping sound, depending on the modulation characteristics of the field. Typical pulse durations resulting in these effects are on the order of a few tens of microseconds.

To summarise, biological effects of high frequency fields are proved to be hazardous only if the radiation intensity is rather high. In the case of most environmental HF exposures, particularly radio base station antennas and cellular phones, the intensity usually does not exceed the adopted exposure limits.

4.5 Electromagnetic Fields and Cancer

A considerable number of epidemiological reports, carried out particularly during the 1980s and 1990s, indicated that a long-term exposure to 50/60 Hz magnetic fields might be associated with cancer [8]. In general, the initially observed associations between 50/60 Hz magnetic fields and various cancers were not confirmed. However, there is evidence for a relationship between extremely low frequency (ELF) fields and childhood Leukemia [19- 23]. Also, the lack of consistent evidences in experimental studies weakens the belief that this association is due to ELF fields. Considering available epidemiological evidence concerning ELF exposure, the conclusion is that there is no solid evidence linking electric and magnetic field exposure to cancer.

The World Health Organisation's International Agency for Research on Cancer (IARC) evaluation of ELF fields [9], published in June 2002, classified power frequency magnetic fields as possibly carcinogenic to humans (Group 2B). According to the same monograph [9], static electric and magnetic fields and extremely low-frequency electric fields are not classifiable as to their carcinogenicity to humans (Group 3). According to IARC monograph published in May 2011 [10], the radio-frequency fields are classified as possibly carcinogenic to humans (Group 2B). The category 2B is used for agents for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity in experimental animals.

Despite many studies [28 - 35], the evidence for any effect remains highly controversial. However, if electromagnetic fields do have an effect on cancer, then any increase in risk will be extremely small. The results to date contain many inconsistencies, but no large increases in risk have been found for any cancer in children or adults.

4.6 EMF and Nerve Simulation

According to the publication "A Neurobiological Basis for ELF Guidelines, 2007" [12] and the ICNIRP 2010 on low frequency guidelines [13], exposure to EMFs can induce electric fields within the body, which for frequencies up to 10MHz can stimulate nerves. The effect of this stimulation varies as a function of frequency. As the frequency increases, heating effects predominates and the likelihood of nerve simulation decreases.

4.7 EMF and Changes to Permeability of Cell Membranes

An intense and brief pulsed EMFs may cause cell membranes to become permeable, which in turn can lead to other cellular changes. According to the 2015 publication on permeability of Gram-positive cocci by EMF [15], membrane permeability changes were shown to occur with 18GHz continuous wave exposure. A significantly higher exposure levels than those required to cause thermally induced harm or nerve stimulation, are required for this effect to occur. Therefore, it is expected that the restrictions on nerve stimulations and temperature rise are sufficient to ensure that permeability changes do not occur.

4.8 EMF and Temperature Rise

At higher frequencies for example radio frequencies, EMFs can generate heat in the body. For very low exposure levels comparable to the basic restrictions provided in ICNIRP 2010 [7], there is extensive evidence that the amount of heat generated is not sufficient to cause harm, but limited research conclusion is available for exposure levels higher than the ICNIRP 2010 basic restriction levels.

It should be noted that the ICNIRP 2020 Guidelines, like other EMF Guidelines, restricts the radio-frequency EMF exposure to limit temperature rise rather than limiting absolute temperature. The absolute temperature is the main cause of the health effect; however, it is not solely dependent on EMF exposure as other factors such as weather condition, clothing and work rate all also contribute to this. For this reason, the aim of the Guideline is to limit significant rise in temperature. Where other sources of heat are present, for example work environment, it is advised that workers have a suitable means of verifying their body temperature [17].

As EMF frequency increases, exposure of the body and the resultant heating becomes more superficial. According to the work by Sasaki et al. [16], at frequencies above 6GHz, this heating occurs predominantly within the skin because of skin penetration depth effect at higher frequencies. The work showed that 86% of the power at 6 and 300 GHz is absorbed within 0.2mm of the surface respectively. There are obviously other possible health effects, which will depend on the extent and intensity of exposure to EMF. Over the years, specific limits have been derived empirically that inhibit the above key known health effects from occurring. These limits are specific to the EMF frequency, as differing risks are posed at different frequencies. It is also expected that compliance with these limits will also prevent other adverse health effects. No adverse health effect has been identified for exposure below the specified limits.

4.9 EMF and Fertility, Reproduction, and Childhood Development

The studies by Lindbohm et al. [24] suggested an association between ELF magnetic fields from Video Display Units (VDUs) and miscarriage. However, the studies by Schnorr et al. [25] found no such association. There is no consistent evidence on adverse reproductive health issue with women working with VDU. A prospective study that included large numbers of cases, had high participation rates, and detailed exposure assessment (Bracken et al. [26]) reported that neither birth weight nor intra-uterine growth rate was related to any ELF field exposure. Adverse outcomes were not associated with higher levels of exposure.

Similar conclusion can be made for exposure at higher frequencies as the studies do not present any consistent evidence. While some of the studies [37] – [38] suggest increased risk of miscarriage and birth defects for female plastic welders and physiotherapist working with shortwave diathermy devices, other publications such as Källen. B.; et al. [39], showed no statistically significant effect on the rate of abortion or foetal malformation.

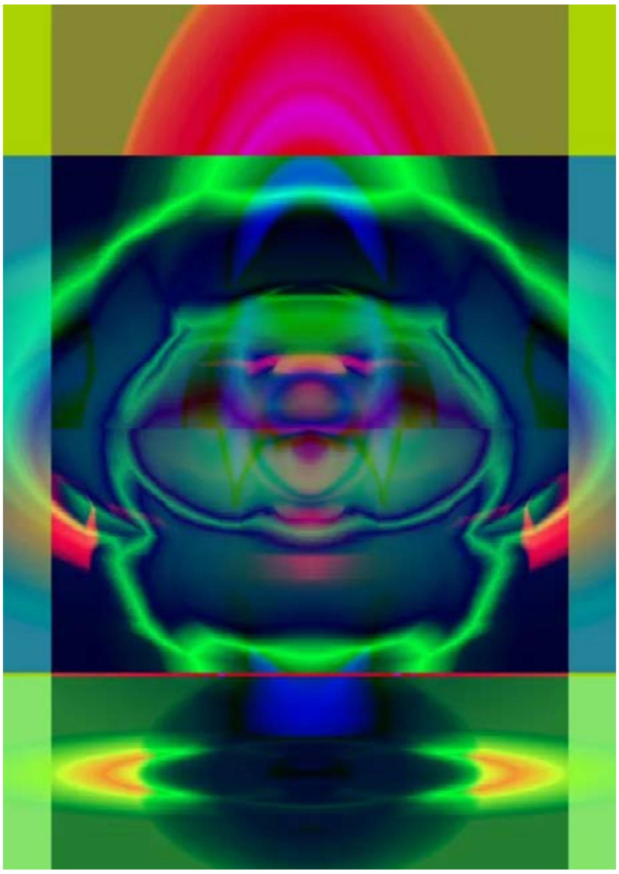


Figure 13: Foetus development in EMF environment

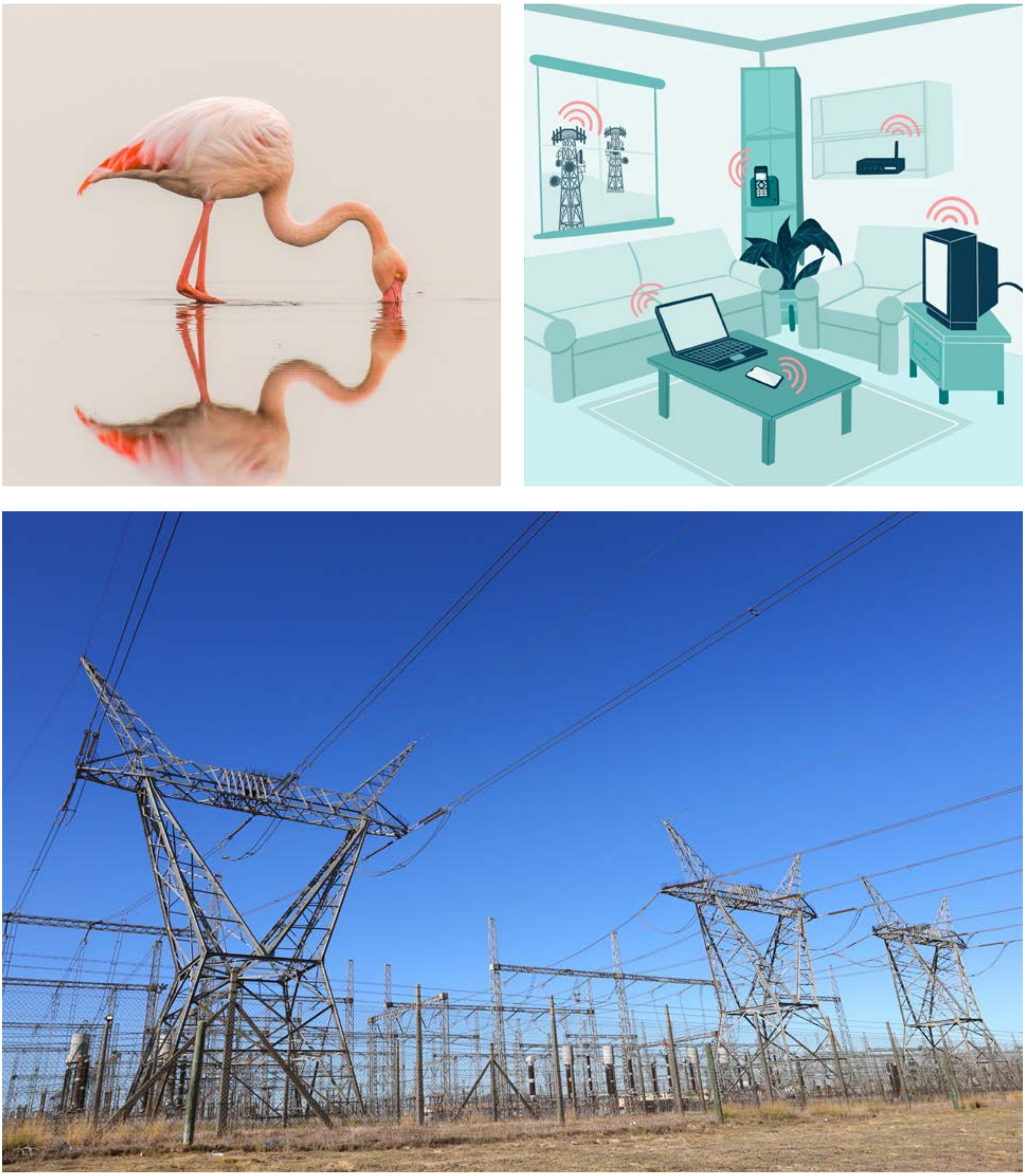


Figure 14: Safety Guidelines and Exposure limits

The approach adopted in this guideline for the control of EMF is in accordance with the method employed in ICNIRP publications.

5 PROTECTION

5.1 Overview of Protection against EMF Exposure

The protection of humans exposed to electromagnetic fields (EMF) is the ultimate goal of a health-based EMF standards. Safety guidelines for the exposure to electromagnetic fields rely upon a well-established effect based on the experimental data from biological systems, on epidemiological and human studies, as well as on understanding of the various interaction mechanisms.

General steps in the development of exposure standards include the evaluation of a large body of scientific literature, followed by setting the threshold levels, the selection of appropriate safety factors for different categories of populations at risk, and finally derivation of the exposure limits. The safety or the exposure limit is considered as that threshold below which exposure can be considered safe according to the available scientific knowledge.

Nevertheless, the safety limit does not represent an exact boundary between safety and hazard, since the possible risk to human health increases with the increasing exposure levels. For efficient protection against the harmful exposure effects, the regulatory agencies, in addition to setting safety limits, need to incorporate a safety margin to allow for the uncertainty.

5.2 Basic Restriction

These are restrictions on exposure to EMF that are based directly on established health effects. In the range from 1Hz to 100 KHz, the physical quantity used to specify the basic restrictions on exposure to EMF is the internal electric field strength E_i, as it is the electric field that affects nerve cells and other electrically sensitive cells. The range from 100 kHz to 10 MHz is considered intermediate range. In the range from 100 kHz to 300 GHz, the basic restrictions are related to whole-body average Specific Absorption Radiation (SAR).

Note that for the basic restrictions described below, a pregnant woman is treated as a member of the general public. This is because recent modelling suggests that for both whole-body and local exposure scenarios, exposure of the mother at the occupational basic restrictions can lead to foetal exposures that exceed the general public basic restrictions. The guidelines take a whole-body average SAR of 4 W/kg

The set of basic restrictions (from ICNIRP 2010 and ICNIRP 2020) given in tables 3–6.

Table 3: Basic restrictions for human exposure to time-varying electric and magnetic fields (ICNRP 2010)

Exposure characteristic	Frequency range	Internal electric field (V m^{-1})
Occupational exposure		
CNS tissue of the head	1 Hz– 10 Hz	0.5/f
	10 Hz–25 Hz	0.05
	25 Hz–400 Hz	$2 \times 10^{-3} f$
	400 Hz–3 kHz	0.8
	3 kHz–10 MHz	$2.7 \times 10^{-4} f$
All tissues of head and body	1 Hz–3 kHz	0.8
	3 kHz–10 MHz	$2.7 \times 10^{-4} f$
General public exposure		
CNS tissue of the head	1–10 Hz	$0.1/f$
	10 Hz–25 Hz	0.01
	25 Hz–1000 Hz	$4 \times 10^{-4} f$
	1000 Hz–3 kHz	0.4
	3 kHz–10 MHz	$1.35 \times 10^{-4} f$
All tissues of head and body	1 Hz–3 kHz	0.4
	3 kHz–10 MHz	$1.35 \times 10^{-4} f$

Notes:

- *f is the frequency in Hz.*
- *All values are rms.*
- *In the frequency range above 100 kHz, RF specific basic restrictions need to be considered additionally.*

Table 4: Basic restrictions for electromagnetic field exposure from 100 kHz to 10 MHz, for peak spatial values

Exposure scenario	Frequency range	Induced electric field; E_{ind} (V m^{-1})
Occupational	100 kHz to 10 MHz	$2.70 \times 10^{-4} f$
General public	100 kHz to 10 MHz	$1.35 \times 10^{-4} f$

Note: f is frequency in Hz

Table 5: Basic restrictions for electromagnetic field exposure from 100 kHz to 300 GHz, for averaging intervals ≥6 min *(ICNIRP 2020)*

Exposure scenario	Frequency range	Whole-body average SAR (W kg^{-1})	Local Head/Torso SAR (W kg^{-1})	Local Limb SAR (W kg^{-1})	Local S_{ab} (W m^{-2})
Occupational	100 kHz to 6 GHz	0.4	10	20	NA
	>6 to 300 GHz	0.4	NA	NA	100
General public	100 kHz to 6 GHz	0.08	2	4	NA
	>6 to 300 GHz	0.08	NA	NA	20

Notes:

1. *"NA" signifies "not applicable" and does not need to be taken into account when determining compliance.*
2. *Whole-body average SAR is to be averaged over 30 min.*
3. *Local SAR and S_{ab} exposures are to be averaged over 6 min.*
4. *Local SAR is to be averaged over a 10-g cubic mass.*
5. *Local S_{ab} is to be averaged over a square 4-cm^2 surface area of the body. Above 30 GHz, an additional constraint is imposed, such that exposure averaged over a square 1-cm^2 surface area of the body is restricted to two times that of the 4-cm^2 restriction.*

Table 6: Basic restrictions for electromagnetic field exposure from 100 kHz to 300 GHz, for integrating intervals >0 to <6 min. *(ICNIRP 2020)*

Exposure scenario	Frequency range	Local Head/Torso SA (kJ kg^{-1})	Local Limb SA (kJ kg^{-1})	Local U_{ab} (kJ m^{-2})
Occupational	100 kHz to 400 MHz	NA	NA	NA
	>400 MHz to 6 GHz	$3.6[0.05+0.95(t/360)^{0.5}]$	$7.2[0.025+0.975(t/360)^{0.5}]$	NA
	>6 to 300 GHz	NA	NA	$36[0.05+0.95(t/360)^{0.5}]$
General public	100 kHz to 400 MHz	NA	NA	NA
	>400 MHz to 6 GHz	$0.72[0.05+0.95(t/360)^{0.5}]$	$1.44[0.025+0.975(t/360)^{0.5}]$	NA
	>6 to 300 GHz	NA	NA	$7.2[0.05+0.95(t/360)^{0.5}]$

Notes:

1. *"NA" signifies "not applicable" and does not need to be taken into account when determining compliance.*
2. *t is time in seconds, and restrictions must be satisfied for all values of t between 0 and 360 s, regardless of the temporal characteristics of the exposure itself.*
3. *Local SA is to be averaged over a 10-g cubic mass.*
4. *Local U_{ab} is to be averaged over a square 4-cm^2 surface area of the body. Above 30 GHz, an additional constraint is imposed, such that exposure averaged over a square 1cm^2 surface area of the body is restricted to $72[0.025+0.975(t/360)^{0.5}]$ for occupational and $14.4[0.025+0.975(t/360)^{0.5}]$ for general public exposure.*
5. *Exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in t s, must not exceed these levels.*

5.3 Reference Level

The internal electric field strength is difficult to assess. Therefore, for practical exposure assessment purposes, reference levels of exposure are provided. Most reference levels are derived from relevant basic restrictions using measurement and/or computational techniques but some address perception (electric field) and adverse indirect effects of exposure to EMF. The derived quantities are electric field strength (E), magnetic field strength (H), magnetic flux density (B) and currents flowing through the limbs (I_L).

Quantities that address perception and other indirect effects are contact current and, for pulsed fields, specific energy absorption (SA). In any particular exposure situation, measured or calculated values of any of these quantities can be compared with the appropriate reference level. Compliance with the reference level will ensure compliance with the relevant basic restriction. If the measured or calculated value exceeds the reference level, it does not necessarily follow that the basic restriction will be exceeded. However, whenever a reference level is exceeded, it is necessary to test compliance with the relevant basic restriction and to determine whether additional protective measures are necessary. These are provided in Tables 7 to 14.

Table 7: Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms values) (ICNIRP 2010)

Frequency range	E-field strength E (kV m^{-1})	Magnetic field strength H (A m^{-1})	Magnetic flux density B (T)
1 Hz–8 Hz	20	$1.63 \times 10^5/f^2$	$0.2/f^2$
8 Hz–25 Hz	20	$2 \times 10^4/f$	$2.5 \times 10^{-2}/f$
25 Hz–300 Hz	$5 \times 10^2/f$	8×10^2	1×10^{-3}
300 Hz–3 kHz	$5 \times 10^2/f$	$2.4 \times 10^5/f$	$0.3/f$
3 kHz–10 MHz	1.7×10^{-1}	80	1×10^{-4}

Note: f represents frequency in Hz.

Table 8: Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values). (ICNIRP 2010)

Frequency range	E-field strength E (kV m^{-1})	Magnetic field strength H (A m^{-1})	Magnetic flux density B (T)
1 Hz–8 Hz	5	$3.2 \times 10^4/f^2$	$4 \times 10^{-2}/f^2$
8 Hz–25 Hz	5	$4 \times 10^3/f$	$4 \times 10^{-3}/f$
25 Hz–50 Hz	5	1.6×10^2	2×10^{-4}
50 Hz–400 kHz	$2.5 \times 10^2/f$	1.6×10^2	2×10^{-4}
400 Hz–3 kHz	$2.5 \times 10^2/f$	$6.4 \times 10^4/f$	$8 \times 10^{-2}/f$
3 kHz–10 MHz	8.3×10^{-2}	21	2.7×10^{-5}

Note: f represents frequency in Hz.

Table 9: Reference levels for local exposure to electromagnetic fields from 100 kHz to 10 MHz (unperturbed rms values), for peak values (ICNIRP 2010)

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V m^{-1})	Incident H-field strength; H_{inc} (A m^{-1})
Occupational	100 kHz–10 MHz	170	80
General public	100 kHz–10 MHz	83	21

Table 10: Reference levels for time-varying contact currents from conductive objects (ICNIRP 2010)

Exposure characteristics	Frequency range	Maximum contact current (mA)
Occupational exposure	Up to 2.5 kHz 2.5–100 kHz 100 kHz–10 MHz	1.0 $0.4f$ 40
General public exposure	Up to 2.5 kHz 2.5–100 kHz 100 kHz–10 MHz	0.5 $0.2f$ 20

Note: f is the frequency in kHz.

Table 11: Reference levels for exposure, averaged over 30 min and the whole body, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values) (ICNIRP 2020)

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V m^{-1})	Incident H-field strength; H_{inc} (A m^{-1})	Incident power density; S_{inc} (W m^{-2})
Occupational	0.1–30 MHz	$660/f_M^{0.7}$	$4.9/f_M$	NA
	>30–400 MHz	61	0.16	10
	>400–2000 MHz	$3/f_M^{0.5}$	$0.008/f_M^{0.5}$	$f_M/40$
	>2–300 GHz	NA	NA	50
General public	0.1–30 MHz	$300/f_M^{0.7}$	$2.2/f_M$	NA
	>30–400 MHz	27.7	0.073	2
	>400–2000 MHz	$1.375/f_M^{0.5}$	$0.0037/f_M^{0.5}$	$f_M/200$
	>2–300 GHz	NA	NA	10

Notes:

1. *"NA" signifies "not applicable" and does not need to be taken into account when determining compliance.*
2. f_M *is frequency in MHz.*
3. S_{inc}*,* E_{inc} *or* H_{inc} *are to be averaged over 30 min, over the whole-body space. Temporal and spatial averaging of each of* E_{inc} *and* H_{inc} *must be conducted by averaging over the relevant square values.*
4. *For frequencies of 100 kHz to 30 MHz, regardless of the far-field/near-field zone distinctions, compliance is demonstrated if neither* E_{inc} *or* H_{inc} *exceeds the above reference level values.*
5. *For frequencies of >30 MHz to 2 GHz: (a) within the far-field zone: compliance is demonstrated if any of the* S_{inc}*,* E_{inc} *or* H_{inc}*, does not exceed the above reference level values (only one is required);*
6. *For frequencies of >2 GHz to 300 GHz: (a) within the far-field zone: compliance is demonstrated if* S_{inc} *does not exceed the above reference level values;*

Table 12: Reference levels for local exposure, averaged over 6 min, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values) (ICNIRP 2020)

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V m^{-1})	Incident H-field strength; H_{inc} (A m^{-1})	Incident power density; S_{inc} (W m^{-2})
Occupational	0.1–30 MHz	$1504/f_M^{0.7}$	$10.8/f_M$	NA
	>30–400 MHz	139	0.36	50
	>400–2000 MHz	$10.58/f_M^{0.43}$	$0.0274/f_M^{0.43}$	$0.29/f_M^{0.86}$
	>2–6 GHz	NA	NA	200
	>6–<300 GHz	NA	NA	$275/f_G^{0.177}$
	300 GHz	NA	NA	100
General public	0.1–30 MHz	$671/f_M^{0.7}$	$4.9/f_M$	NA
	>30–400 MHz	62	0.163	50
	>400–2000 MHz	$4.72/f_M^{0.43}$	$0.0123/f_M^{0.43}$	$0.058/f_M^{0.86}$
	>2–6 GHz	NA	NA	40
	>6–<300 GHz	NA	NA	$55/f_G^{0.177}$
	300 GHz	NA	NA	20

Notes:

1. *"NA" signifies "not applicable" and does not need to be taken into account when determining compliance.*
2. f_M *is frequency in MHz;* f_G *is frequency in GHz.*
3. S_{inc}*,* E_{inc}*, and* H_{inc} *are to be averaged over 6 min, and where spatial averaging is specified in Notes 6–7, over the relevant projected body space. Temporal and spatial averaging of each of Einc and Hinc must be conducted by averaging over the relevant square values.*
4. *For frequencies of 100 kHz to 30 MHz, regardless of the far-field/near-field zone distinctions, compliance is demonstrated if neither peak spatial Einc or peak spatial Hinc, over the projected whole-body space, exceeds the above reference level values.*
5. *For frequencies of >30 MHz to 6 GHz: (a) within the far-field zone, compliance is demonstrated if one of peak spatial* S_{inc}*,* E_{inc} *and* H_{inc}*, over the projected whole-body space, does not exceed the above reference level values (only one is required);*
6. *For frequencies of >6 GHz to 300 GHz: (a) within the far-field zone, compliance is demonstrated if* S_{inc}*, averaged over a square 4-* cm^2 *projected body surface space, does not exceed the above reference level values;*
7. *For frequencies of >30 GHz to 300 GHz, exposure averaged over a square 1-*cm^2 *projected body surface space must not exceed twice that of the square 4-*cm^2 *restrictions.*

Table 13: Reference levels for local exposure, integrated over intervals of between >0 and <6 minutes, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values) (ICNIRP 2020)

Exposure scenario	Frequency range	Incident energy density; U_{inc} ($kJ\,m^{-2}$)
Occupational	100 kHz–400 MHz	NA
	>400 MHz–2000 MHz	$0.29/f_M^{0.86} \times 0.36\,[0.05+0.95(t/360)^{0.5}]$
	>2–6 GHz	$200 \times 0.36\,[0.05+0.95(t/360)^{0.5}]$
	>6–<300 GHz	$275/f_G^{0.177} \times 0.36\,[0.05+0.95(t/360)^{0.5}]$
	300 GHz	$100 \times 0.36\,[0.05+0.95(t/360)^{0.5}]$
General public	100 kHz–400 MHz	NA
	>400 MHz–2000 MHz	$0.058/f_M^{0.86} \times 0.36\,[0.05+0.95(t/360)^{0.5}]$
	>2–6 GHz	$40 \times 0.36\,[0.05+0.95(t/360)^{0.5}]$
	>6–<300 GHz	$55/f_G^{0.177} \times 0.36\,[0.05+0.95(t/360)^{0.5}]$
	300 GHz	$20 \times 0.36\,[0.05+0.95(t/360)^{0.5}]$

Note:

1. *”NA” signifies “not applicable” and does not need to be taken into account when determining compliance.*
2. f_M *is frequency in MHz;* f_G *is frequency in GHz;* t *is time interval in seconds, such that exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in t seconds, must not exceed these reference level values.*
3. U_{inc} *is to be calculated over time* t*, and where spatial averaging is specified, over the relevant projected body space.*
4. *For frequencies of 100 kHz to 400 MHz, >0 to <6-min restrictions are not required and so reference levels have not been set.*
5. *For frequencies of >400 MHz to 6 GHz: (a) within the far-field zone: compliance is demonstrated if peak spatial* U_{inc}*, over the projected whole-body space, does not exceed the above reference level values;* U_{eq} *may be substituted for* U_{inc}*; (b) within the radiative near-field zone, compliance is demonstrated if peak spatial* U_{inc}*, over the projected whole-body space, does not exceed the above reference level values; and (c) within the reactive near-field zone, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.*
6. *For frequencies of >6 GHz to 300 GHz: (a) within the far-field or radiative near-field zone, compliance is demonstrated if* U_{inc}*, averaged over a square 4-cm*^{2} *projected body surface space, does not exceed the above reference level values; (b) within the reactive near-field zone, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.*
7. *For frequencies of >30 GHz to 300 GHz: exposure averaged over a square 1-cm*^{2} *projected body surface space must not exceed* $275/f_G^{0.177} \times 0.72[0.025+0.975(t/360)^{0.5}]$ *kJ/m*^{2} *for occupational and* $55/f_G^{0.177} \times 0.72\,[0.025+0.975(t/360)^{0.5}]$ *kJ/m*^{2} *for general public exposure.*

The threshold contact currents that elicit biological responses in children and adult women are approximately one-half and two-thirds, respectively, of those for adult men. For the frequency range 100 kHz–110 MHz, reference levels are provided for limb currents that are below the basic restrictions on localized SAR.

Table 14: Reference levels for current induced in any limb, averaged over 6 min, at frequencies from 100 kHz to 110 MHz (ICNIRP 2020)

Exposure scenario	Frequency range	Electric current; I (mA)
Occupational	100 kHz–110 MHz	100
General public	100 kHz–110 MHz	45

Note:

1. *Current intensity values must be determined by averaging over the relevant square values.*
2. *Limb current intensity must be evaluated separately for each limb.*
3. *Limb current reference levels are not provided for any other frequency range.*
4. *Limb current reference levels are only required for cases where the human body is not electrically isolated from a ground plane.*

6 REAL LIFE SCENARIOS

The increase in technology consumption and system electrification, have placed a huge demand in electricity supplies both for residential use and in the workplace, required to power the associated devices. Both the consumer equipment and the circuit required for transmitting electricity from the generator to end user, are sources of EMF.

Whilst the high voltage transmission circuits are often located away from areas accessible to the public as a way of controlling EMF and other risks, the various end user equipment can still pose a threat because of the manner it is used. More so as these devices operate at varying frequencies, often in GHz, safety measures are required in order to ensure that exposure to harmful levels of EMF is prevented. A common safety measure is the derivation of a protection distance from the EMF source, beyond which the level of EMF has been estimated or observed to be safe.

In this section, results from existing studies, together with electromagnetic emission assessment of these typical sources of EMF are presented.

6.1 Case One: Household Appliances

Electrical and electronics appliances (non-radio equipment) can produce varying levels of electric and magnetic fields. These are non-intentional emitters but are capable of generating EMFs due to the operations of the active circuitry components and power supply.

As explained earlier in this document, the magnitude of these fields will be higher at locations closer to the appliance. For the appliance, emissions at power frequency magnetic fields are more predominant than electric fields. The level of emissions from various devices are independent of size and complexity. Manufacturers and designers often integrate various electromagnetic screening methods so as to suppress these emissions. An old appliance will likely generate higher emissions.

In recent years, national authorities in different countries have conducted many measurements to investigate electromagnetic field levels in the living environment. None of these surveys has concluded that field levels could bring about adverse health effects. According to the WHO [51], the 1999 publication by the Federal Office for Radiation Safety in Germany, provided values (as shown in Table 15 and Table 16) for electric and magnetic fields produced by typical appliances.

Table 15: Typical electric field strengths (at 50 Hz) measured near household appliances (at a distance of 30 cm)

Electric Appliance	E- Field Strength Vm^{-1}
Stereo receiver	180
Iron	120
Refrigerator	120
Mixer	100
Toaster	80
Hairdryer	80
Colour TV	80
Coffee Machine	60
Vacuum Cleaner	50
Electric Oven	8
Light Bulb	5

The 50Hz power frequency EMF exposure limit for electric field is 5,000 Vm^{-1}. Therefore at 30 cm from these devices, the exposure limit for electric field should not be exceeded.

Table 16: Typical magnetic field strengths (at 50Hz) of household appliances at various distances

Electric Appliance	3 cm distance (μT)	30 cm distance (μT)	1 m distance (μT)
Hair Dryer	6–2000	0.01–7	0.01–0.03
Electric Shaver	15–1500	0.08–9	0.01–0.03
Vacuum Cleaner	200–800	2–20	0.13–2
Fluorescent Light	40–400	0.5–2	0.02–0.25
Microwave Oven	73–200	4–8	0.25–0.6
Portable Radio	16–56	1	<0.01
Electric Oven	1–50	0.15–0.5	0.01–0.04
Washing Machine	0.8–50	0.15–3	0.01–0.15
Iron	8–30	0.12–0.3	0.01–0.03
Dishwasher	3.5–20	0.6–3	0.07–0.3
Computer	0.5–30	<0.01	–
Refrigerator	0.5–1.7	0.01–0.25	<0.01
Colour TV	2.5–50	0.04–2	0.01–0.15

The 50Hz power frequency EMF exposure limit for magnetic field is 200 μT for the public. This shows that the limit should not be exceeded at 30 cm, and also that the fields reduce rapidly with distance.

6.2 Case Two: HV Power Lines

Overground and underground high voltage (HV) power lines are often used in the distribution and transmission of electricity from the generating system to the consumer sites. These lines are capable of producing electric and magnetic fields, with relatively high fields observed close to the circuit.

The examples presented in this assessment are three phases system as shown in Figure 16. The tab 17 indicates the parameters of the High voltage line 1 (HVL1) and high voltage line 2 (HVL2).

Table 17: Parameters of the high voltage line

	Voltage (kV)	Current (A)	Sag (m)	Span (m)
HVL1	161	485	9.6	400
HVL2	400	2000	9.6	400

Figure 16: High voltage transmission line L220 of the Electrical Community of Benin (CEB)

The following figures show electric and magnetic field measurement results obtained below the overhead transmission lines at a height 1.5 m above the earth. The figures 17 and 19 show respectively the lateral electric and magnetic field profile as a function of the distances. The figures 18, 20, 21 and 22 show electric and magnetic field distribution in the plane of the overhead transmission lines [53] [54].

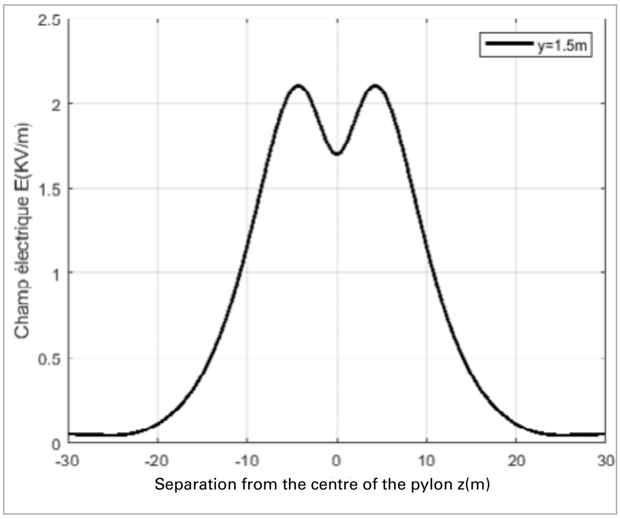


Figure 17: Profile of electric field under a 161 kV, 50-Hz line, at height 1.5m above ground, Sag = 9,68 m (From: Romaric Adegbola, 2022)

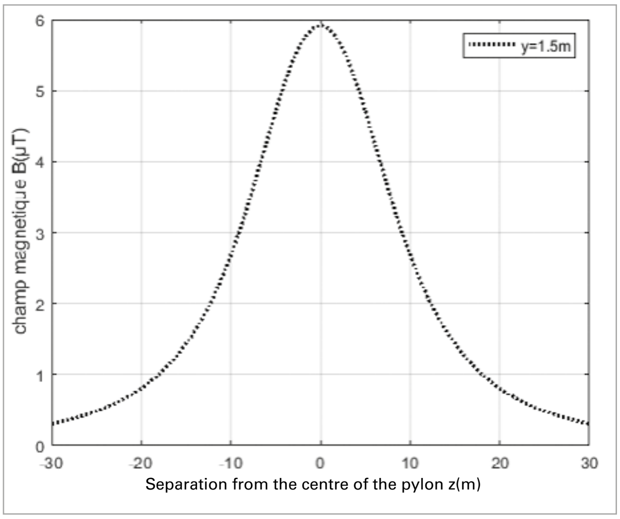


Figure 19: Distribution profile of magnetic field under a 485 A, 50Hz line, at height 1.5 m above ground, Sag = 9,68 m (From: Romaric Adegbola, 2022)

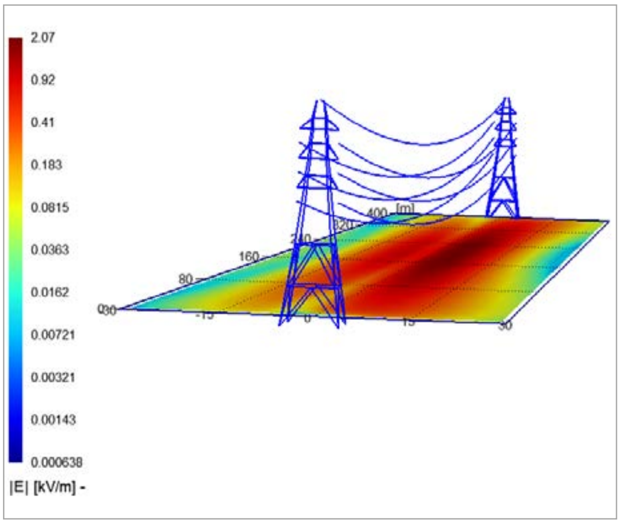


Figure 18: Distribution profile of electric field under a 161 kV, 50-Hz line, at height 1.5m above ground, Sag = 9,68 m (From: Romaric Adegbola, 2022)

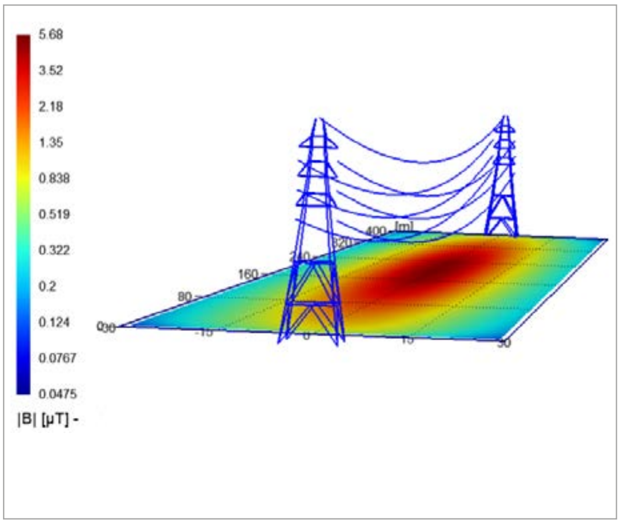


Figure 20: Profile of magnetic field under a 485 A, 50Hz line, at height 1.5 m above ground, Sag = 9,68 m (From: Romaric Adegbola, 2022)

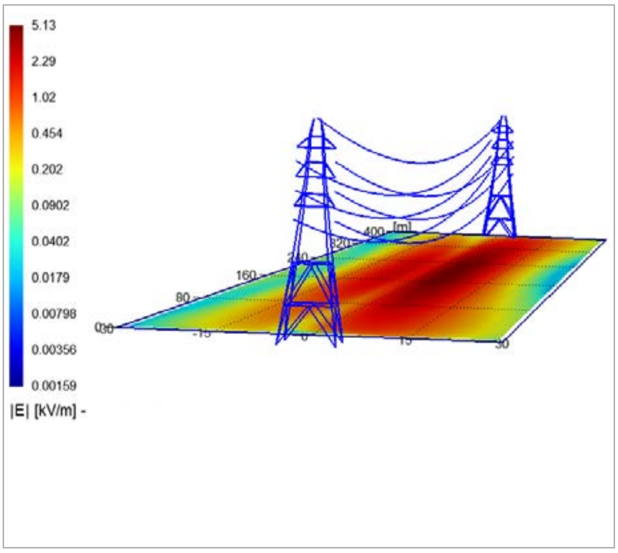


Figure 21: Distribution profile of electric field under a 400 kV, 50-Hz line, at height 1.5m above ground, Sag = 9,68 m (From: Romaric Adegbola, 2022)

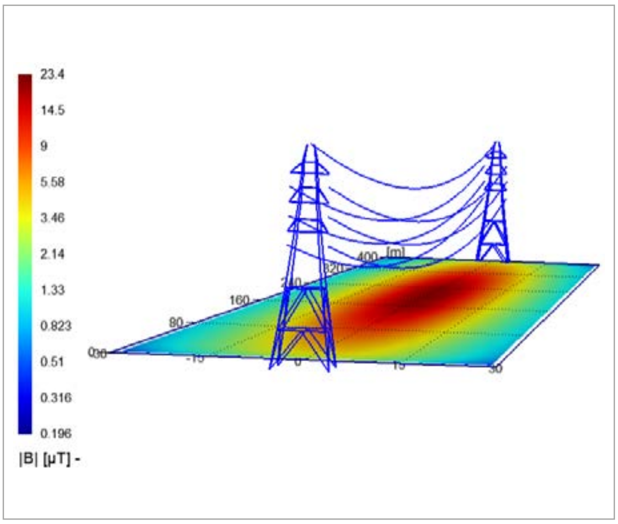


Figure 22: Profile of magnetic field under a 2000 A, 50Hz line, at height 1.5 m above ground, Sag = 9,68 m (From: Romaric Adegbola, 2022)

The measurement of the electric and magnetic fields revealed that there were some areas in the vicinity of the overhead high voltage transmission lines where the electric and magnetic fields intensity has exceeded the maximum allowed exposure values for the general public or for workers. However, the electric and magnetic fields decreased based on distance from source to field point. Besides, electric field is produced based on voltage applied on phase conductor and the magnetic field is produced based on current flowing in the phase conductor. Also, load demands influence the magnetic field values.

In contrast to an electric field, a magnetic field is more penetrating and very difficult to shield. It easily penetrates human beings and, in the case of an alternating or rotating field, induces circulating or eddy currents that are not conducted to ground.

In principle, these magnetic fields can induce electric currents in the body and could induce effects via the same mechanisms as electric field-produced currents. However, for exposures near a High Voltage transmission line, the smaller magnitude of these magnetically induced currents has resulted in little emphasis on their contribution.

Furthermore, results show how the field diminishes as one moves away from the pylon.

Table 18: Protection Distances for Power Line.

Magnetic Field Limits	Contour Lines, dBμ (A/m)	Protection Distance
100μT (for general public defined in ICNIRP 1998, Council Recommendation 1999/519/EC)	158.02	3m from the nearest phase conductor (about 23m from the centre of the pylon)
1000pT (for workers defined in 2013/35/EU)	178.02	Not exceed

Table 19: Exposure limits to low frequency electric and magnetic fields (50 Hz) ICNIRP (2010)

	Residential Exposure Limits	Workplace/ Industry Exposure Limits
Electric Field	5kV/m	10kV/m
Magnetic Field	200μT	1000μT

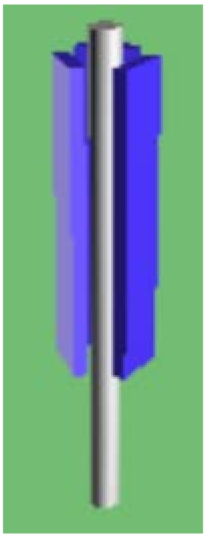
6.3 Case Three: Radio Systems

These are mainly intentional emitters and comprise fixed and mobile radio equipment. At their operating frequencies, the electric field is predominant. So, for this assessment, electric field emissions were used to characterise the EMF.

Radio equipment suppliers are required to meet certain safety criteria, and this is crucial especially for mobile radio equipment, as the proximity and duration of use by most end users can increase the risk. For example, the EU Radio Equipment Directive 2014/53/EU requires protection of the end users from health issues, with the obligation placed on the importers. For the radio systems assessment, the parameters are the following, 40W of power, 17(dBi) of Gain, frequencies of 900-1800-2200-2600 MHz, 0.5m of length and 27 m of pylon high.

Picture of sector antenna

Simulated model of sector antenna



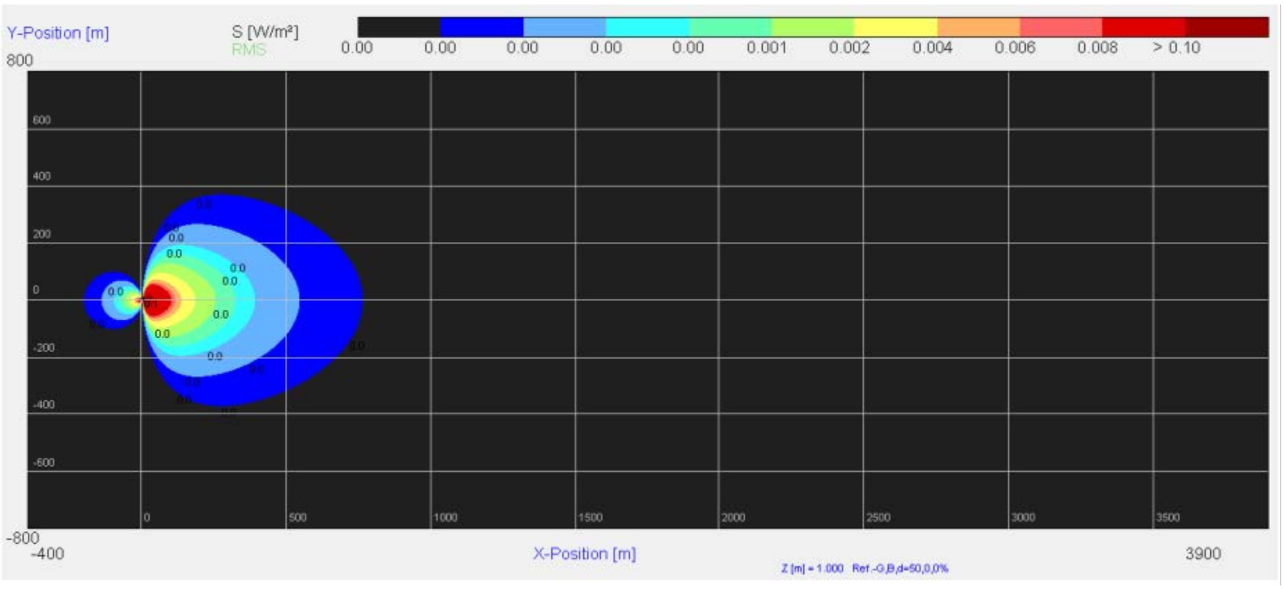


Figure 23: Radiated power density diagram of mono-sector antenna in XY plan

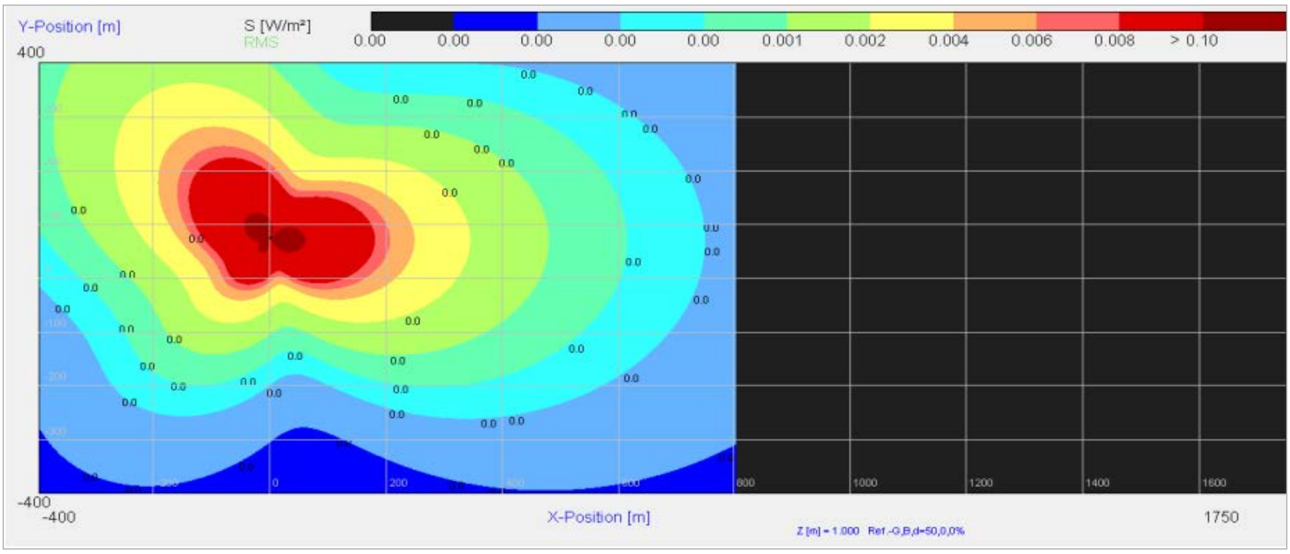


Figure 24: Electromagnetic field profile for radio wave antenna, length = 0.5m, pylon high = 27 m, frequencies = 900-1800-2200-2600 MHz, power = 40W, Gain (dBi) = 17. (From: Romaric Adegbola, 2018)

Table 20: Electromagnetic limitation exposure high frequencies ICNIRP (2020)

Frequencies ranges	Electric field	Magnetic field	Power density
0.1-30 MHz	$671\,/f_M^{0.7}$	$4.49\,/f_M$	-
30-400MHz	62	0.163	10
400-2000MHz	$4.72\,/f_M^{0.43}$	$0.123\,/f_M^{0.43}$	$0.058\,/f_M^{0.86}$

In high frequencies the protection distance around antenna is function of antenna parameters. The table shows the protection distance in function of antenna parameters.

This study results, summarised in Table 21 are taken from environmental impact study of the terrestrial numerical television Department of the Republic of Benin (study carried out by Romaric Adegbola and Amevi Acakpovi in 2017).

The results for the radio system generated EMF show that the mobile radios such as user telephones, pose relatively higher threat than the fixed radio antenna mounted on a mast. Therefore, limitation of the duration of mobile phone use in proximity is recommended. Based on the review of the existing works and assessment carried out by AFSEC, we summarise the following:

- Electrical appliances differ greatly in the strength of fields they generate. Both electric and magnetic field levels decrease rapidly with distance from the appliances. In any event, fields surrounding household appliances usually are far below guideline limits.

- At operator positions the electric and magnetic fields of television sets and computer screens are hundreds of thousands of times below guideline levels.

- Microwave ovens meeting standard specifications are not hazardous to health.

- As long as close public access to radar facilities, broadcasting antennas and mobile phone base stations is restricted, exposure guideline limits for radio-frequency fields will not be exceeded.

- The user of a mobile phone encounters field levels that are much higher than any levels in the normal living environment. However, even these increased levels do not appear to generate harmful effects.

- Many surveys have demonstrated that exposure to electromagnetic field levels in the living environment is extremely low.

Table 21: Protection distance in function of antenna parameters

	Power (w)	Gain (dBi)	Freq (MHz)	Electric field (not exceed) V/m	Protection distance (m)	Electric field (measured) V/m (at 10m from antenna)
Antenna 1	3000	15.75	570	33	48	27.3
Antenna 2	3000	17.55	570	33	58	33.6
Antenna 3	1000	13.95	570	33	22	12.8
Antenna 4	1000	13.95	570	33	22	12.8
Antenna 5	3000	15.75	498	31	56	27.3
Antenna 6	1000	10.15	538	32	16	8.3

7 ADDITIONAL PROTECTIVE MEASURES

ATC 77 notes that the industries causing exposure to electric and magnetic fields are responsible for ensuring compliance with all aspects of the guidelines. Measures for the protection of workers include engineering and administrative controls, personal protection programs, and medical surveillance. Appropriate protective measures must be implemented when exposure in the workplace results in the basic restrictions being exceeded. As a first step, engineering controls should be undertaken wherever possible to reduce device emissions of fields to acceptable levels. Such controls include good safety design and, where necessary, the use of interlocks or similar health protection mechanisms.

Administrative controls, such as limitations on access and the use of audible and visible warnings, should be used in conjunction with engineering controls. Personal protection measures, such as protective clothing, though useful in certain circumstances, should be regarded as a last resort to ensure the safety of the worker; priority should be given to engineering and administrative controls wherever possible. Furthermore, when such items as insulated gloves are used to protect individuals from high-frequency shock and burns, the basic restrictions must not be exceeded, since the insulation protects only against indirect effects of the fields.

With the exception of protective clothing and other personal protection, the same measures can be applied to the general public whenever there is a possibility that the general public reference levels might be exceeded. It is also essential to establish and implement rules that will prevent:

- interference with medical electronic equipment and devices (including cardiac pacemakers);
- detonation of electro-explosive devices (detonators); and
- fires and explosions resulting from ignition of flammable materials by sparks caused by induced fields, contact currents, or spark discharges.

8 CONCLUSION

In summary, this guide on EMF Exposure summarises many facts about exposure to EMF, their consequences for human, the protection measures available and more importantly the exposure limits as documented in relevant standards. Starting with background information on EMF exposure, the possible risks for tissues and organs exposed to EMF, the guidelines delved deeply into the biological effect of EMF exposure. The guidelines further provide a summary of protection measures appropriate for domestic and industrial areas and further stressed on the exposure limits referenced from the ICNIRP and ICES publications. Furthermore, three case studies were presented in the end to illustrate real life scenarios where EMF exposures were tested and compared against acceptable exposure limits. These guidelines represent a summary of extremely vital and important information relevant to EMF exposure looking at their expansion and possible harmful effect on biological tissues and organs, amidst the ever growing digital era.

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