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Human Exposure to Electromagnetic Field and Electromagnetic Compatibility

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The main objective of this study was to clarify the safety viewpoint of regulations of electric, magnetic and electromagnetic fields. Nowadays the environment is polluted with the EMF, thus we might have harmful electric, magnetic or electromagnetic radiations which might have an impact on the metabolism of our body or malfunction of medical devices like a pacemaker.

The theoretical information in this report was collected from various websites and articles. It includes information and history of the EMC regulations and standards. In addition to this, the exposure limits that a human body can accept at a different level of frequencies are presented in this report. It includes a static magnetic field (0 Hz), static electric field (0 Hz), low frequency (1 Hz – 100 kHz) and high frequency (100 kHz – 300 GHz).

The thesis is also a part of a recommendation for KONE, as the company is interested in making an application of an inductive power transfer which induces strong electromagnetic field. To implement that, this report could be reviewed and the prototype could be designed in such a way that there won’t be any issues related to the effect on health and medically implanted devices. We don’t know the actual frequency used in inductive power transfer so the study has been made in the various level of frequencies. Thus, this report could be reviewed as a general report with respect to the frequency needed for inductive power transfer.

Keywords	EMC, magnetic field, electric field, human body model, low frequency, high frequency, exposure limit, reference level, Peripheral and central nervous system, Specific absorption rate.

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Appendix 1: Table of Exposure Character at Different frequencies.
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Abbreviations

EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMF	Electromagnetic Field
Hz	Hertz
WHO	World Health Organisation
HF	High Frequency
LF	Low Frequency
RF	Radio Frequency
HVDC	High Voltage Direct Current
AC	Alternating Current
DC	Direct Current
MRI	Magnetic Resonance Imaging
ECG	Electro Cardiac Diagram
EMS	Electromagnetic Susceptibility
IEC	Electro technical Commission
EEG	Electroencephalography

SAR	Specific Absorption Rate
PNS	Peripheral Nervous Stimulation
CNS	Central Nervous Stimulation
ICNIRP	International Commission for Non-Ionizing Radiation Protection
ESD	Electrostatic Discharge

IMPORTANT CONCEPTS

Exposure Limit: It is the value established based on biophysical and biological considerations, in particular based on scientifically well-established short term and acute direct effects.

Basic Restriction: It is the limiting EMF exposure that will provide protection against adverse health effect.

Reference Level OR Action Level: The reference levels are obtained from the basic restrictions by mathematical modeling and from the results of laboratory investigations at specific frequencies.

Specific Absorption Rate (SAR): It is the rate at which energy is absorbed per unit mass of body tissue and expressed in watt per kilogram (Wkg^{-1}). SAR is widely accepted quantity for relating adverse thermal effects to radio frequency exposure.

1 Introduction

This thesis is divided into two parts. The first part deals and explains the principle of the physical basis which are important to understand the second part and is the review of the existing standards.

Many consumers, industrial products and applications use some form of the electromagnetic energy. In this digital era, life without them seems to be impossible. Together with the advancement and digitalisation of the technology, we always have an issue with the electromagnetic interference (EMI), and the number of products produced are having a significant effect on the efforts aimed at maintaining the required operation of products and systems used in our society. In addition to that, the use of integrated circuit and large size integration has reduced to a size of the electronic equipment and has become more sophisticated and more circuits are crowded into small space which has increased the probability of interferences. As the density of the electromagnetic environment continues to increase, the concern about its effects from sources producing EMI also increases and it is likely to become more severe and worse in the coming future, as the electronic circuit is widely spread in various aspects like communication, automation, computation, medication and many other.

Together with the interference with other electronic equipment, the concern with the health issues has created a problematic situation. Today's engineering requires to operate in ideal condition with no interferences that are harmful either to the electronic equipment or to the health of the living beings. Besides that, obvious task, products must be designed to work in the ‘‘real world,’’ with other equipment nearby, and to comply with government electromagnetic compatibility (EMC) regulations. This means that the equipment should not be affected by external electromagnetic sources and should not itself be a source of electromagnetic noise that can pollute the environment.

The automotive industry is growing day by day, and those technologies need to be updated time and again. Lift Car is very often seen everywhere and to get upgraded for this kind of technology, it is intended to be made wireless. At the same time, the concern regarding the Electromagnetic Compatibility always comes at the first position. Along with the approach of Inductive Power Transfer, various EMI should be taken into consideration.

2 Literature Background to Physical Basics

Literature background focuses on the theoretical knowledge required in order to accomplish the project. The required topics, formulas with its derivations are shown.

2.1 Lorentz Forces Laws

Lorentz force is the force exerted on a charged particle *q* moving with velocity *v* through an electric *E* and magnetic field *B*. The entire electromagnetic force *F* on the charged particle is called the Lorentz force and is given by equation 1.

$$F = qE + qv \times B \quad (1)$$

A simple apparatus demonstrates that something happens when charges are in motion, if we run currents next to one another in parallel, we find that they are attracted when the currents run in the same direction; they are repulsed when the currents run in opposite directions as shown in Figure 1. Even though wires are completely neutral: if we put a stationary test charge near the wires, it feels no force. (Hughes, 2005)

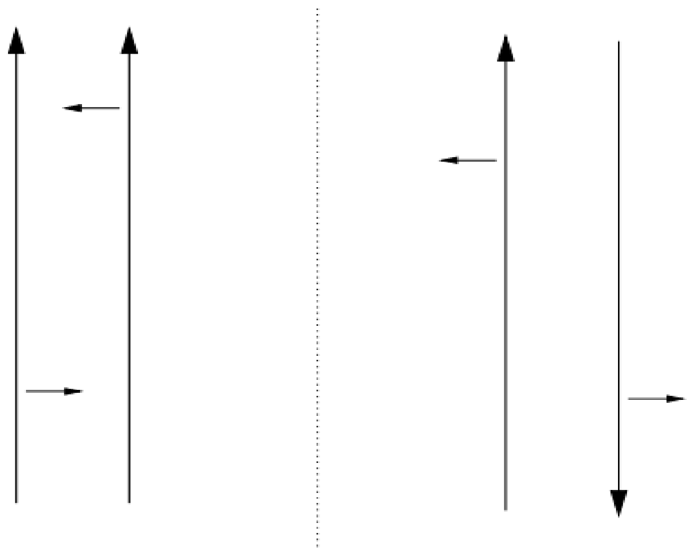


Figure 1: Left: parallel currents attract. Right: Anti-parallel currents repel. (Hughes, 2005)

Furthermore, experiments show that the force is proportional to the currents - double the current in one of the wires, and you double the force. Double the current in both wires, and you quadruple the force. (Hughes, 2005)

This all indicates a force that is proportional to the velocity of a moving charge; and, that points in a direction perpendicular to the velocity. These conditions are screaming for a force that depends on a cross product. What we say is that a kind of field B, the “magnetic field”- arises from the current. The direction of this field is kind of odd: it wraps around the current in a circular fashion, with a direction that is defined by the right-hand rule. We point our right thumb in the direction of the current, and our fingers curl in the same sense as the magnetic field as shown in Figure 2. (Hughes, 2005)

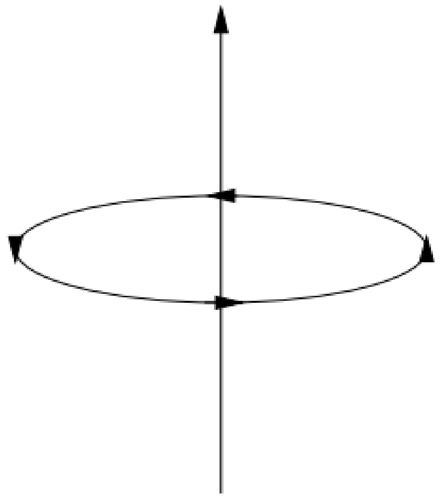


Figure 2: Right hand thumb rule

With this sense of the magnetic field defined, the force that arises when a charge moves through this field and is given by equation 2.

$$F = q\,(v \times B) \qquad (2)$$

This force law is known as the Lorentz force.

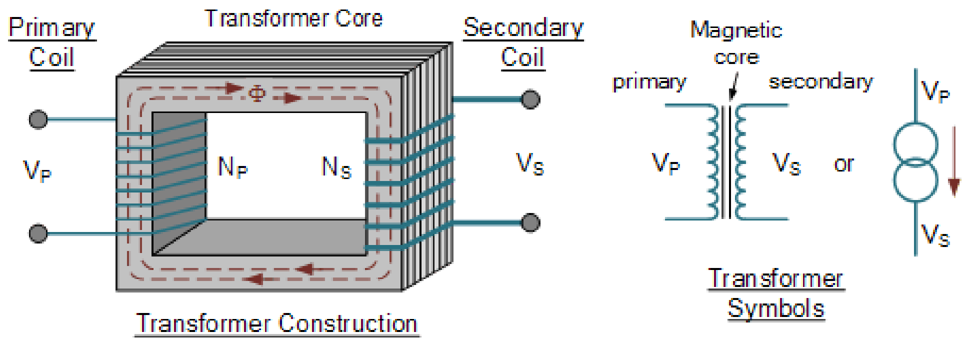
2.2 Transformer

The transformer is an electrical device that changes the voltages in the Alternating current (AC) and transfers electrical energy between two or more circuits through electromagnetic induction.

A unique property of electricity is that a magnetic field is produced around a wire in which an electrical current is flowing. More the amount of the current flowing, the stronger will be the magnetic field. A winding of the wire into a coil delivers a strong magnetic field. The alternating current flowing through the transformer first flows in one direction, stops and changes its direction. A constant motion of magnetic field is observed around the winding in the coil. (AspenCore, Inc., 2016)

At the same time, electricity follows another property in the operation of the transformer. The movement of the magnetic field across a wire induces the voltage on it. If a complete circuit is made, then a current flow through the wire. Another coil placed in a moving magnetic field induces a voltage in the same coil. Thus, this phenomenon is called the mutual inductance. Alternating current in one winding produces a moving magnetic field that induces a voltage in another winding. The electrical energy is first converted into a magnetic field and again to the electrical energy with little or no loss of energy. (AspenCore, Inc., 2016)

2.3 Transformer Construction



Where:
- V_P – is the Primary Voltage
- V_S – is the Secondary Voltage
- N_P – is the Number of Primary Windings
- N_S – is the Number of Secondary Windings
- Φ (phi) – is the Flux Linkage

Figure 3: A single phase Transformer (AspenCore, Inc., 2016)

Figure 3 shows a single-phase transformer in which the coils are not connected electrically but are linked magnetically. The transformer used to increase the voltage on secondary winding with respect to the primary winding is called the Step-up transformer. The transformer used to decrease the voltage on the secondary winding with respect to the primary is called the step-down transformer. There is a transformer which produces the same voltage on the secondary as applied to primary winding i.e. output is identical with respect to voltage, current and power transferred. This type of transformer is called the Isolation transformer and is mainly used for the isolation of adjoining electrical circuits, usually for safety reasons. The voltage difference could be achieved by changing the number of the turns of primary winding with respect the secondary winding.
(AspenCore, Inc., 2016)

Transformers are all about "ratios". The ratio of the primary to the secondary, the ratio of the input to the output, and the turns ratio of any given transformer will be the same as its voltage ratio. In other words, for a transformer: "turns ratio = voltage ratio" and this relationship is given as: (AspenCore, Inc., 2016)

$$\frac{Np}{Ns} = \frac{Vp}{Vs} = n = \text{Turns Ratio} \qquad (3)$$

In an ideal transformer, the power available in the secondary winding will be the same as the power in the primary winding, they are constant devices and do not change the power but only the voltage to current ratio. Thus, in an ideal transformer the Power Ratio is equal to one (unity) as the voltage, V multiplied by the current, I will remain constant. (AspenCore, Inc., 2016)

$$\text{Power}_{\text{Primary}} = \text{Power}_{\text{secondary}} \qquad (4)$$

$$V_p I_p \cos \Phi_p = V_s I_s \cos \Phi_s \qquad (5)$$

2.4 Inductive Coupling

Inductive Coupling is the Interference created by the magnetic field induced by a rapid change in current inside a wire.

When current ***I*** Flows through a conductor, it produces a magnetic flux ***Φ,*** which is proportional to the current. The constant of proportionality is the inductance *L*; hence,

$$\Phi_T = LI, \tag{6}$$

Where Φ_T is the total magnetic flux and *I,* is the current producing the flux. Rewriting, we get for the self-inductance of a conductor

$$L = \frac{\Phi T}{I}. \tag{7}$$

The inductance depends on the geometry of the circuit and the magnetic properties of the media containing the field. (Ott, 2009). When current flow in one circuit produces a flux in a second circuit, there is a mutual inductance M_{12} between circuits 1 and 2 defined as

$$M_{12} = \frac{\boldsymbol{\Phi}12}{I1} \tag{8}$$

The symbol $\boldsymbol{\Phi}_{12}$ represents the total flux in circuit 2 because of the current I_1 in circuit 1. The voltage V_N induced in a closed loop of area, *A* resulting from a magnetic field of flux density *B* can be derived from Faraday's law

$$V_N = \frac{d}{dt}\int_A \overline{B} \cdot d\overline{A} \tag{9}$$

where *B* and *A* are vectors. If the closed loop is stationary and the flux density is sinusoidal varying with time but constant over the area of the loop, reduces to

$$V_N = \omega BA \tag{10}$$

A is the area of the closed loop, *B* is the root mean square (RMS) value of the sinusoidal varying flux density of frequency ω radians per second, and V_N is the RMS value of the induced voltage. (Ott, 2009, p. 52)

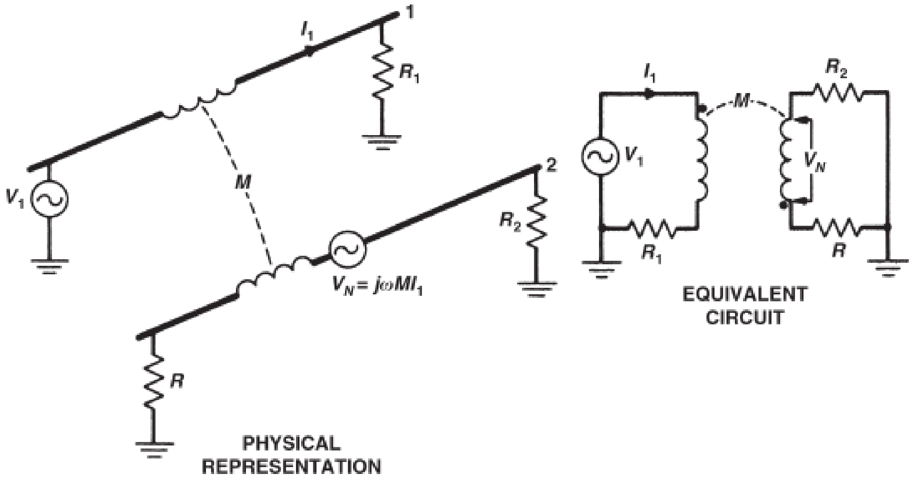


Figure 4: Circuit diagram presenting Inductive coupling. *(Ott, 2009, p. 53)*

Because *BA* represents the total magnetic flux ($\boldsymbol{\Phi}_{12}$) coupled to the receptor circuit, Equations can be combined to express the induced voltage in terms of the mutual inductance M between two circuits, as follows:

$$V_N = jwMI_1 = M\frac{di_1}{dt} \tag{11}$$

This is the basic equation describing the inductive coupling between two circuits. Figure 4 shows the inductive (magnetic) coupling between two circuits as described by the equation, the current in the interfering circuit, and M is the term that accounts for the geometry and the magnetic properties of the medium between the two circuits. The presence of ω indicates that the coupling is directly proportional to frequency. (Ott, 2009, p. 53)

3 Electromagnetic Compatibility

According to European EMC directive 2004/108/EC, EM compatibility means the ability of equipment to function satisfactorily in its EM environment without introducing intolerable EM disturbances to other equipment in that environment.

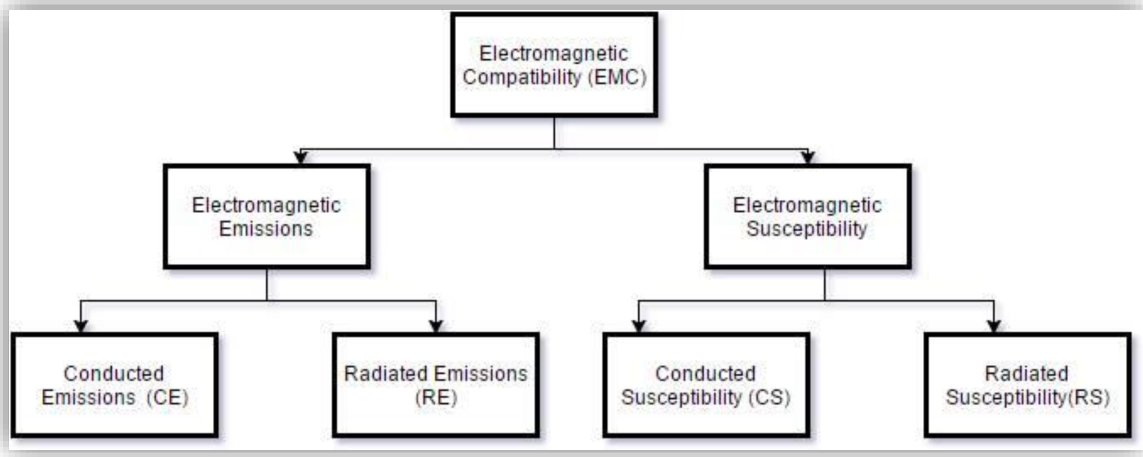


Figure 5. Areas of electromagnetic compatibility

Electromagnetic Compatibility requires us to view disturbances from two distinct viewpoints; electromagnetic emission and electromagnetic susceptibility. They are produced by conduction and radiation. Electromagnetic emission is a kind of radiation including visible light, radio waves, gamma rays, and X-rays, in which electric and magnetic fields vary simultaneously whereas electromagnetic susceptibility is the malfunction of the electrical equipment in the presence of unwanted emissions. Figure 5 shows the areas of electromagnetic compatibility.

3.1 Structure of the EMF Directive

The Treaty of Rome (now the Treaty on the Functioning of the European Union) sets an objective to encourage improvements in the working environment regarding the health and safety of workers. To help achieve this objective it allows for the introduction of directives to set minimum requirements. In 1989 the Framework Directive (89/391/EEC) was introduced as an overarching directive in this area. The Framework Directive sets out general requirements for assessing and reducing risks, emergency preparedness, worker information, participation and training, worker obligations, and health surveillance. It also provides for the introduction of individual directives, which essentially give additional detail on how to achieve the objectives of the Framework Directive in specific situations. Figure 6 illustrates how it fits into the broader legislative landscape. (Directive 2013/35/EU, 2013)

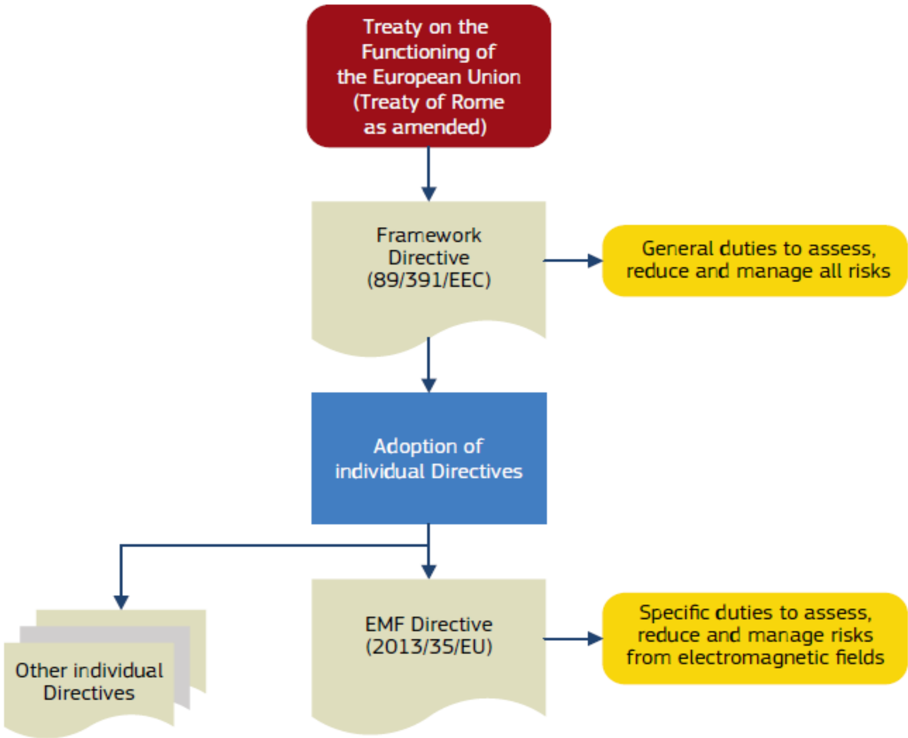


Figure 6: Schematic representation of legislative setting of EMF directive (Directive 2013/35/EU, 2013)

The EMF Directive is intended to help employers achieve compliance with their obligations under the Framework Directive for the specific situation of work that involves exposure to EMF. It follows that many of the requirements of the EMF Directive mirror those in the more general Framework Directive and hence the two Directives should be used together. The main emphasis of the EMF Directive is to assess risks arising from electromagnetic fields in the workplace and then, if necessary, put in place measures to reduce them. However, one result of the linkage between the two Directives is that most employers who are already meeting their obligations under the Framework Directive should find that they have little more to do in order to achieve compliance with the EMF Directive. (Directive 2013/35/EU, 2013)

The EMF Directive seeks to introduce minimum requirements for health and safety in relation to work with EMF. In line with the Treaty on the Functioning of the European Union, individual Member States may choose to maintain existing legislation or introduce new legislation with requirements that are more stringent than those in the EMF Directive. Figure 7 summarises the interaction between the articles. (Directive 2013/35/EU, 2013)

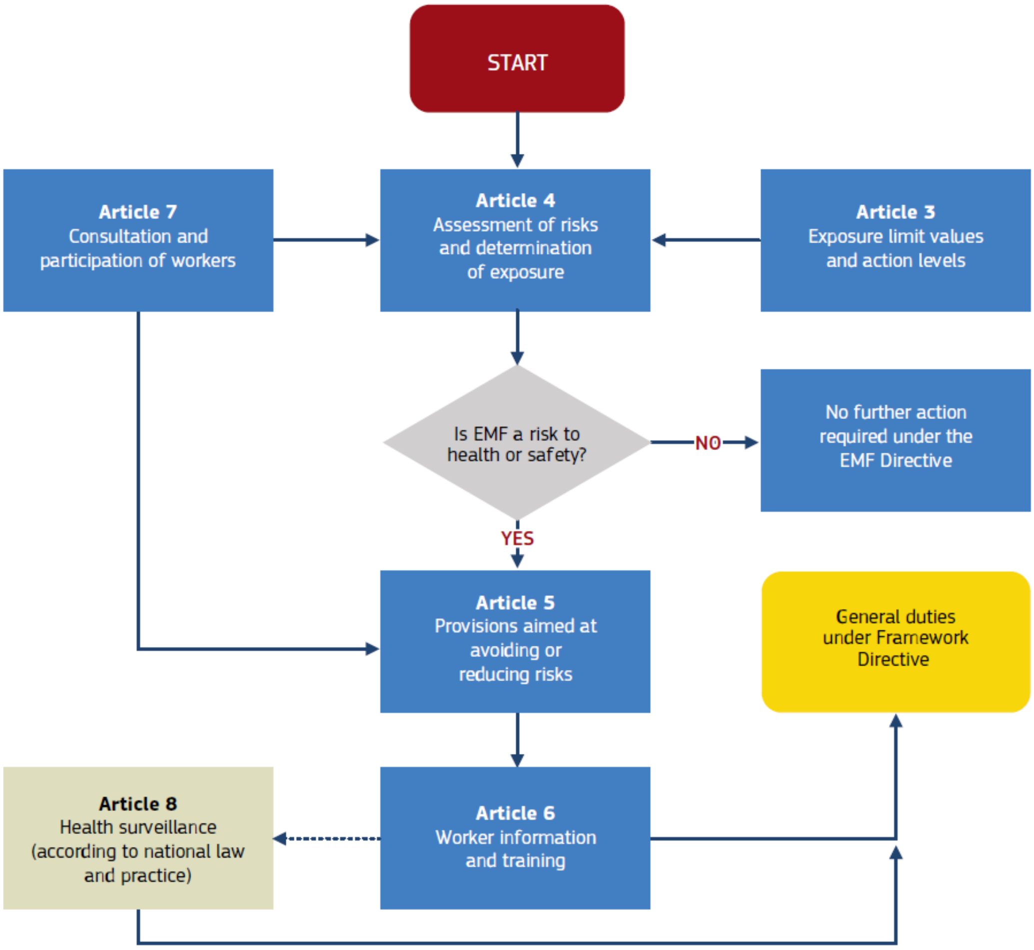


Figure 7: Schematic showing interaction between articles (Directive 2013/35/EU, 2013)

3.2 EMI Types

The various type of EMI is shown in Figure 6 and are as follows:

1. Conductive*:* Interference conducted through physically connect coupling
2. Inductive: Interference created by the magnetic field induced by a rapid change in current inside a wire.

3. Capacitive: Occurs when unshielded cables with high impendence are near each other and work like capacitors broadcasting the signal to other cables nearby through an electric field.

4. Radiative: Originates from high-frequency antennas (>50 MHz) used for mobile phone, radio, and television transmission.

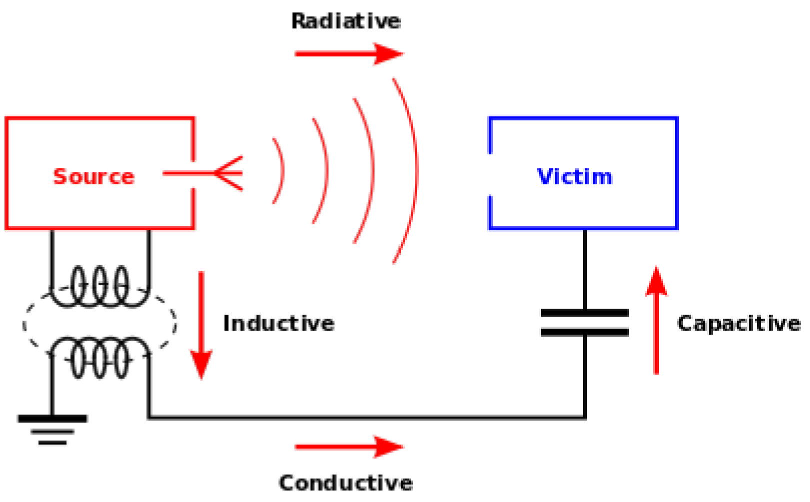


Figure 6: EMI Types

3.3 Electromagnetic Field

Electromagnetic fields, emitted by electrical devices and applications can potentially disturb the human health. EMFs are a part of the non-ionizing radiation spectrum, including static fields (0 Hz) and the time varying EMFs range of 1 Hz to 300 GHz.

EMFs are characterized by their frequency (f) and the wavelength (λ), with units Hertz [Hz] and meter [m], respectively and related to the velocity of the light (c).

$$F = c/\lambda \tag{12}$$

Magnetic fields are generated by the moving charges and characterized by the magnetic field strength (H) expressed in [A/m] and the magnetic flux density (B) in a unit of Tesla (T). Magnetic field strength and flux density are related to the magnetic permeability of the medium (μ).

$$B = \mu H \tag{13}$$

Electric charges produce an electric field around them even without flowing currents. The strength of electric field (E) is expressed in volt per meter [V/m]. Interaction mechanisms of EMFs with a human body depend on the frequency content of the fields. (ICNIRP Publication, 2009)
Static (0 Hz) magnetic fields have electrodynamical and magneto-mechanical effects on the body. Electrodynamical interactions with moving conductive tissue (e.g. cardiac contraction) induce electric fields and currents inside the body, whereas magneto-mechanical interactions result in torques and forces on magnetic materials. In addition, static magnetic fields can affect electronic spin states of reaction intermediates.

Static electric fields do not penetrate the body, but they can induce surface charges on conducting objects which may result in currents through the body when in contact with a grounded person.

Time-varying, extremely low frequency (1 Hz–100 kHz) magnetic fields induce electric fields and circulating electric currents in the body, whereas electric fields with these frequencies produce a surface charge, which results in induced currents in the body. Radio frequency (RF) electric and magnetic fields (100 kHz–300 GHz) are coupled to cells and tissues, and energy is deposited or absorbed in the biological system. Some effects may result from the induced fields and currents, but these mainly are associated with an elevation of tissue temperature from RF energy absorbed in biological systems.

International reference levels for the exposure to EMFs have been established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The reference levels are frequency dependent below the frequency of 3 kHz, and they have been derived separately for general public and occupational exposure. **At the power frequency of 50 Hz, the newest ICNIRP reference levels for public exposure are 200 µT (magnetic field) and 5 kV/m (electric field). Respectively, the reference levels for occupational exposure are 1 mT and 10 kV/m at 50 Hz.** The old reference levels at 50 Hz for public exposure were 100 µT and 5 kV/m and for occupational exposure 500 µT and 10 kV/m, respectively. (See Appendix 2) (ICNIRP Publication, 2009)

4 Description of Electromagnetic Disturbances

Any electrical equipment (especially semiconductors) is a potential source of Electromagnetic interference. HF radiated to the environment will be named as undesired disturbing signals. However, this equipment may generate HF signals not only in the fundamental frequency range but also a wide frequency ranges on both sides of a fundamental carrier like the industrial heat furnaces, high-frequency medical equipment. Some other electrical equipment generates HF signals that are not required for normal operation. This signal appears as electromagnetic noise in the environment. Although levels of the incident signals are relatively low, they often are a major cause of EMI. These includes switches, electrical cleaning equipment, and power electronics equipment. (J.K Eckert & Company, Inc., 1995)

4.1 Disturbances by Frequency

Figure 7 explains the disturbances by the frequency with the source. The frequency ranges of 0 Hz to 30000 THz is shown in the diagram. It is categorized according to the value of the frequency content. The range from 0 Hz - 15 kHz, 15 kHz - 500 MHz and 500 MHz - 300 GHz are Extremely low frequency (ELF), Very low Frequency (VLF) and High Frequency (HF) respectively. (See Appendix 2) The range of Radio Frequency disturbances starts at 150 kHz. Also, the wavelength decreases with the increase in the frequency. (Conductix Wampfler, 2006)

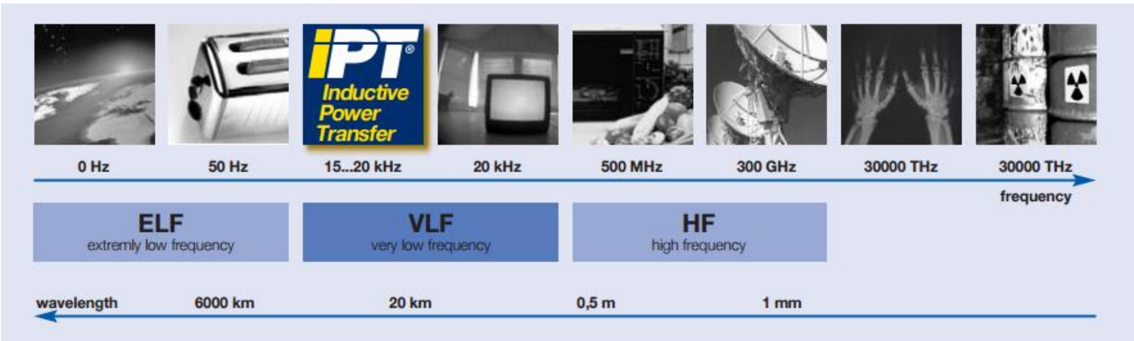


Figure 7: Electromagnetic disturbances by the frequency with sources. (Conductrix Wampfler, 2006)

4.2 Disturbances by Character

Electromagnetic disturbances affect the mains voltage. The disturbances can be short term or long term. Generally, they cause the alternation in the RMS value of the main voltage so thought as a real problem. The duration of short changes only occurs a few seconds or less than a microsecond. (J.K Eckert & Company, Inc., 1995)

The electromagnetic disturbances of short term can be divided into three parts:

1. Noise
   The noise is a periodic character thus has higher repetition frequency than mains frequency. Electronics motors, welding machine are example characteristics of noise sources. Also, the amplitude is less as compared to the peak amplitude of the mains voltage.

2. Impulses
   They are positive and negative peaks in the mains voltage. Impulses are characterized by having a short duration, high amplitude and fast rise and fall times. The devices that produce impulses are switches, rectifier, relay controls.

3. Transients
   It is generally a time period. The time period can range a few periods of the industrial frequency to a few seconds and commonly generate by high power switches.

5 Human Body Model

Human is the prime source of the electrostatic discharge. This charge can be transferred from one person to any piece of sensitive electronic equipment in the form of electrostatic discharge. Human body model behaves as a capacitor and resistor. The primary contributor to the capacitance of the body comes from the capacitance between the soles of the feet and ground which is about 100pF. The additional capacitance of from 50 to 100 pF may exist because of the contact of the person to the surrounding objects, like walls as shown in Figure 8. Thus, the capacitance of the human body varies between 50 and 250pF. (Ott, 2009, p. 587)

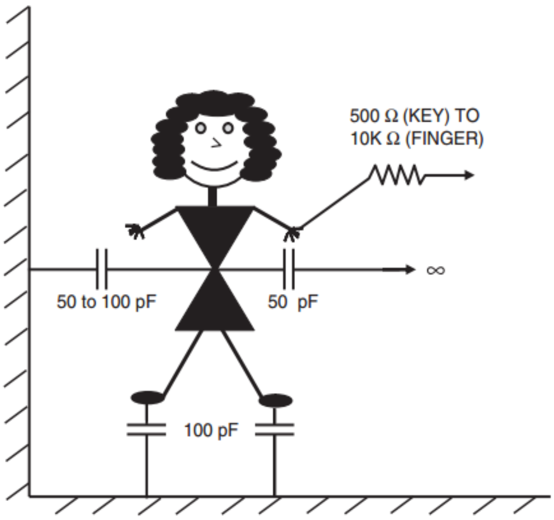


Figure 8: Human Body Model. (Ott, 2009, p. 587)

The human body model for ESD is shown in Figure 9. The body capacitance C_b is charged up to a voltage V_b by triboelectric charging (or other means), and the discharge occurs through the body resistance R_b. The body resistance is important because it limits the discharge current. The body resistance can vary from about 500 to 10,000 ohms, depending on which part of the body the discharge occurs from. If the discharge is from the tip of the finger, then the resistance will be about 10,000 ohms; if from the palm of the hand, about 1000 ohms; if from a small metal object in the hand (e.g., a key or a coin), it will be about 500 ohms. If, however, the discharge occurs from a large metal object in contact with the person, such as a chair or a shopping cart, the resistance can be as low as 50 ohms. (Ott, 2009, p. 588)

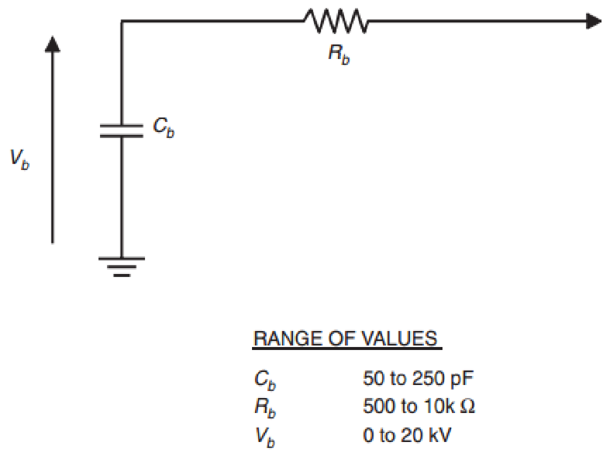


Figure 9: Human body capacitance and resistance. (Ott, 2009, p. 588)

5.1 Direct and Indirect Effects

Direct Biophysical effects means effects in the human body directly caused by its presence in an electromagnetic field, including: (Directive 2013/35/EU, 2013)

1. Thermal effects such as heating of tissues by absorption of energy from electromagnetic fields.
2. Non-thermal effects, such as the stimulation of muscles. Nerves or sensory organs. The stimulation of sensory organs may lead to transient symptoms such as vertigo or phosphenes.
3. Limb currents

Indirect Effects means effects, caused by the presence of an object in an electromagnetic field, such as: (Directive 2013/35/EU, 2013)

1. Interference with medical electronic equipment and devices, including cardia pacemaker and other medically implanted devices.
2. Ferromagnetic objects in static magnetic field.
3. The initiation of electro explosive devices.
4. Contact currents.

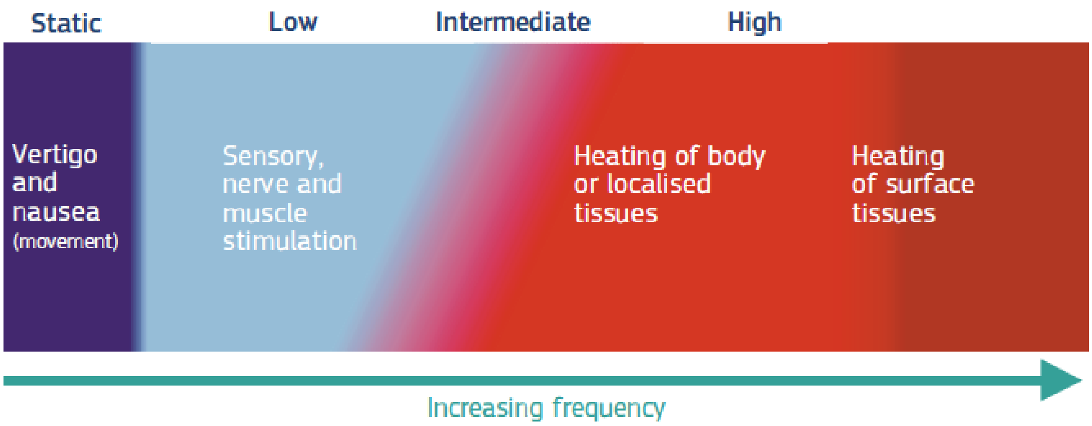


Figure 10: Effects of EMF at different frequency range

6 Frequency Aspects

6.1 Static Magnetic Field (0 Hz)

The static magnetic field is the constant field which is produced either by permanent magnets or flow of the Direct Current (DC) through conducting material. (ICNIRP Publication, 2009).

According to the Biot Savart law, when charges move in a conducting wire and produce a current I, the magnetic field at any point P due to the current can be calculated by adding up the magnetic field contributions, d**B**, from small segments of the wire d**s**.

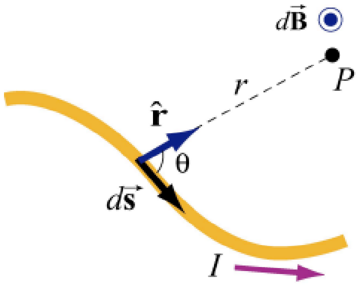


Figure 10: Schematic obeying Biot Savart law.

Let's consider from Figure 10, r is the distance from the current source to the field point P, and $\hat{r}$ the corresponding unit vector. The Biot - Savart law gives an expression for the magnetic field contribution, dB, from the current source, $Id\vec{\mathbf{s}}$

$$d\vec{\mathbf{B}} = \frac{\mu_0}{4\pi}\frac{I\,d\vec{\mathbf{s}}\times\hat{\mathbf{r}}}{r^2} \qquad (14)$$

where μ_o is a constant called the permeability of free space,

$$\mu_o = 4\pi 10^{-7} T.m/A$$

It should be noted that the strength of magnetic flux density is expressed in Tesla but the gauss is still common in use and used in some countries. 10^4 gausses equal to 1T. The strength of the natural geomagnetic field varies from about 30 to 70 µT (1 µT is 10^{-6} T). Household magnets have strengths in the order of several tens of mill tesla (1 mT = 10^{-3} T). By contrast, the fields of MRI equipment vary from between 1.5 to up to as much as 10 T.

6.1.1 Magnetic Environment

At the center of Earth is a conducting iron core in which electric current flows, and hence gives rise to the static magnetic field. In practice the structure of the magnetic field source inside the Earth is complicated and changes after certain time. A world magnetic model is developed by US and UK geological surveys in order to predict the magnetic field over the Earth surface. (Health Protection Agency, 2008).

In Figure 11 below it can be seen that the magnetic field generally ranges from 25 to 60 µT.

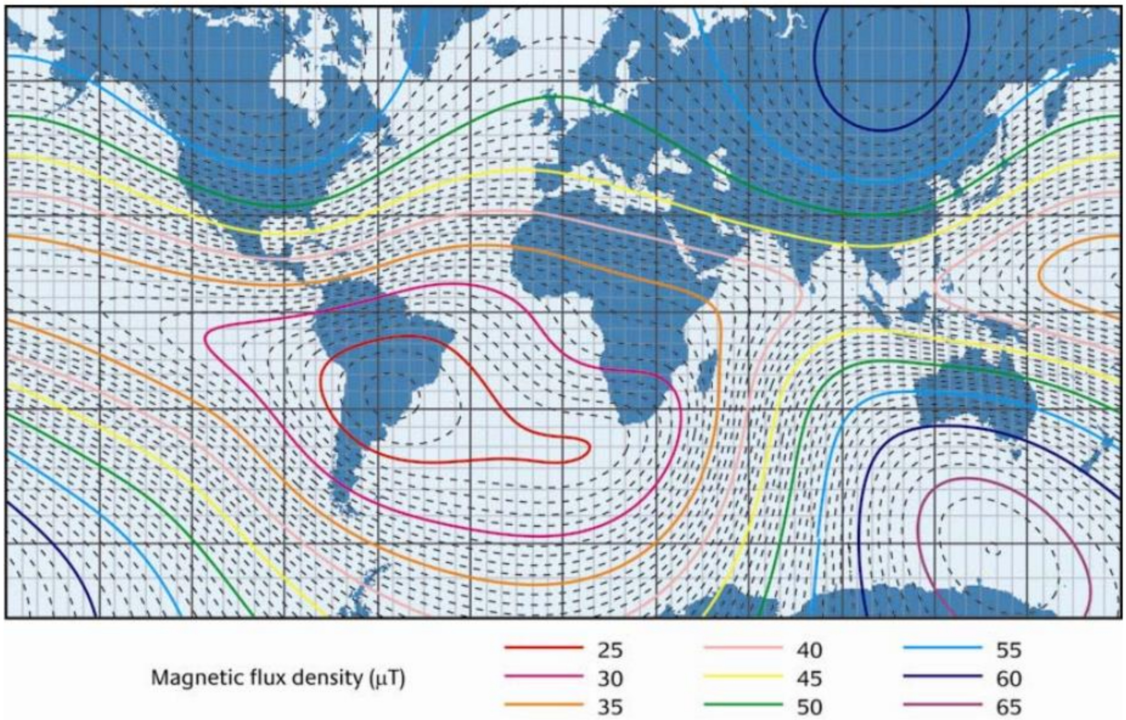


Figure 11: Strength of Geomagnetic field at Earth surface (Health Protection Agency, 2008)

6.1.2 Exposure Limit

There is different guidance given in various categories. It is recommended that the limits for occupational exposure in these guidelines be applied to those individuals who are exposed to static magnetic fields as a result of performing their regular or assigned job activities as shown in *Table 1*. The term "general public" refers to the entire population. (ICNIRP Publication, 2009)

Table 1: Limits of exposure to static magnetic field. (ICNIRP Publication, 2009)

Exposure Characteristics	Magnetic Flux Density (B)
Occupational	
Exposure of head and of trunk	2T
Exposure of limbs	8T
General Public	
Exposure of any part of body	400mT

For static magnetic fields, effects are only likely to occur when there is movement in the field, such as the motion of a person or internal body movements, such as blood flow or heartbeat. A person moving within a field above 2 T can experience sensations of vertigo and nausea, and sometimes a metallic taste in the mouth and perceptions of light flashes.

Occupational exposures

It is recommended that occupational exposure of the head and trunk should not exceed a spatial peak magnetic flux density of 2T except for the following circumstance: for work applications for which exposures above 2T are deemed necessary, exposure up to 8T can be permitted if the environment is controlled and appropriate work practices are implemented to control movement-induced effects. When restricted to the limbs, maximum exposures of up to 8T are acceptable. (ICNIRP Publication, 2009)

General public exposures

Based on scientific knowledge on the direct effects of static fields on humans, acute exposure to the general public should not exceed 400mT (any part of the body). However, because of potential indirect adverse effects, **ICNIRP recognizes that practical policies need to be implemented to prevent inadvertent harmful exposure of people with implanted electronic medical devices and implants containing ferromagnetic materials, and injuries due to flying ferromagnetic objects, and these considerations can lead to much lower restriction levels, such as 0.5mT.** (ICNIRP Publication, 2009)

Action level or the Reference Level for magnetic flux density of static magnetic fields are presented in Table 2.

Table 2: Reference level for magnetic flux density of static magnetic field (Directive 2013/35/EU, 2013)

Hazards	Action Levels (B_o)
Interference with active implanted devices e.g. pacemaker	0.5 mT
Attraction and projectile risk in the fringe field of high field strength sources (> 100 mT)	3 mT

6.1.3 Effects on Human Beings and Implanted Medical Devices

There have been several human studies evaluating the physiological and neurobehavioral influence in humans exposed while stationary to static field up to 8T. There was no impact on the psychological parameters including body temperature, respiratory rate, pulse rate, blood pressure and oxygen level. **Distortion at Electro-cardiac diagram (ECG) was observed However, the heart rate was not affected**. (ICNIRP Publication, 2009)

The electromagnetic interference of low intensity static magnetic fields has an impact on the operation of pacemaker. Particularly with those with magnetic switches and another type of medical electronic devices, including hormone infusion pumps. **In general, static magnetic field does not adversely affect the operation of these device below 0.5mT.** (ICNIRP Publication, 2009)

6.2 Static Electric Field (0 Hz)

Static electric fields are constant fields, which do not change in intensity or direction over time, in contrast to low and high-frequency alternating fields. Hence, static electric fields have a frequency of 0 Hz. They exert a force on charges or charged particles. (ICNIRP, 2016)

The strength of a static electric field is expressed in volts per meter (V/m). The strength of the natural electric field in the atmosphere varies from about 100 V/m in fair weather to several thousand V/m under thunderclouds. Other sources of static electric fields are charge separation because of friction or static electric currents from varied technologies. In the home, charge potentials of several kilovolts can be accumulated while walking on non-conducting carpets, generating local fields of up to 500 kV/m. High voltage DC power lines can produce static electric fields of up to 20 kV/m and more. Inside DC operated electric trains, static electric fields of up to 300 V/m can be found. (ICNIRP, 2016)

6.2.1 Effects on Human and Health Implanted Devices

Static electric fields do not penetrate the human body because of its high conductivity. The electric field induces a surface electric charge, which, if sufficiently large, may be perceived through its interaction with body hair and through other phenomena such as spark discharges (micro shocks). The perception threshold in people depends on various factors and can range between 10 - 45 kV/ m. Furthermore, very high electric fields, such as from HVDC lines, can charge particles in the air, including polluted particles. Current knowledge, however, suggests that an increased health risk from such charging of particles is very unlikely. (ICNIRP, 2016)

Overall, the limited number of animal and human laboratory studies that have investigated the effects of exposure to static electric fields, have not provided evidence of adverse health effects. (ICNIRP, 2016)

6.3 Very Low Frequency (1 Hz – 10 MHz)

The guidelines for the protection of human exposed to the electric and magnetic field are important. The low-frequency range is categorized from 1 Hz to 100 kHz. Studies on both direct and indirect effects of EMF have been assessed, direct effects result from the direct interaction of fields with the body and indirect effect involves with a conducting object where the electric potential of the object is different from that of the body. Human and animal body have the distribution of a low-frequency electric field. At low frequency, the body is a good conductor. Oscillating charges are induced on the surface of the exposed body and these produce currents inside the body. (ICNIRP Publication, 2010)

6.3.1 Exposure Limit

There is different guidance given by ICNIRP in various categories. It is recommended that the limits for occupational exposure in these guidelines be applied to those individuals who are exposed to static magnetic fields as a result of performing their regular or assigned job activities. The term “general public” refers to the entire population. (ICNIRP Publication, 2010)

Separate guidance is given for occupational exposures and exposure of the general public. Occupational exposure in these guidelines refers to adults exposed to time-varying electric, and magnetic fields from 1 Hz to 10 MHz at their workplaces, generally under known conditions, and as a result of performing their regular or assigned job activities. By contrast, the term general population refers to individuals of all ages and of varying health status which might increase the variability of the individual susceptibilities. In many cases, members of the public are unaware of their exposure to EMF. These considerations underlie the adoption of more stringent exposure restrictions for the public than for workers while they are occupationally exposed. (ICNIRP Publication, 2010)

Table 3: Basic restriction for human exposure to time varying electric field. (ICNIRP Publication, 2010)

Exposure characteristic	Frequency range	Internal electric field ($V\ m^{-1}$)
Occupational exposure		
CNS tissue of the head	1–10 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.

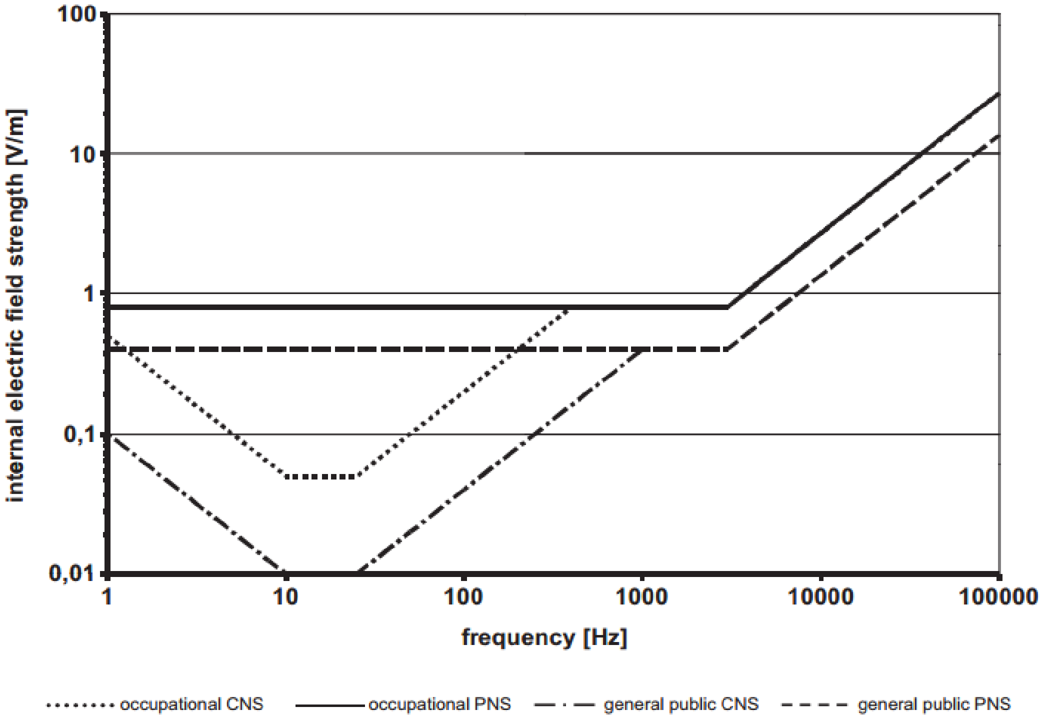


Figure 12: Basic restrictions for general public and occupational exposure in terms of internal electric field strength concerning CNS and PNS effects. (ICNIRP Publication, 2010)

In view of the considerations above for frequencies in the range 10 Hz to 25 Hz, occupational exposure should be limited to fields that induce electric field strengths in CNS tissue of the head (i.e., the brain and retina) of less than 50 mV m^{-1} in order to avoid the induction of retinal phosphenes. These restrictions should also prevent any possible transient effects on brain function. These effects are not considered to be adverse health effects; however, ICNIRP recognizes that they may be disturbing in some occupational circumstances and should be avoided but no additional reduction factor is applied. Phosphene thresholds rise rapidly at higher and lower frequencies, intersecting with the thresholds for peripheral and central myelinated nerve stimulation at 400 Hz. (ICNIRP Publication, 2010)

At frequencies above 400 Hz, limits on peripheral nerve stimulation apply in all parts of the body. Exposure in controlled environments, where workers are informed about the possible transient effects of such exposure, should be limited to fields that induce electric fields in the head and body of less than 800 mV m^{-1} to avoid peripheral and central myelinated nerve stimulation. A reduction factor of 5 has been applied to a stimulation threshold of 4 V m^{-1} in order to account for the uncertainties described above. Such restrictions rise above 3 kHz. (ICNIRP Publication, 2010)

For the general public for CNS tissue of the head a reduction factor of 5 is applied, giving a basic restriction of 10 mV m^{-1} between 10 and 25 Hz. Above and below these values, the basic restrictions rise. At 1000 Hz, it intersects with basic restrictions that protect against peripheral and central myelinated nerve stimulation. Here, the reduction factor of 10 results in a basic restriction of 400 mV m^{-1}, which should be applied to the tissues of all parts of the body. (ICNIRP Publication, 2010).

The basic restrictions are presented in Table 3 and Figure 12.

6.3.2 Reference Level for Electric and Magnetic fields

The reference levels or Action levels are obtained from the basic restrictions by mathematical modeling using published data. They are calculated for the condition of maximum coupling of the field to the exposed individual, thereby providing maximum protection. Frequency dependence and dosimetric uncertainties were considered. The reference levels presented consider two distinct effects and approximate a combination of the induced electric fields in the brain, relevant for CNS effects, and the induced electric fields in non-CNS tissues anywhere in the body, relevant for PNS effects (i.e., at 50 Hz, the factor used to convert the basic restriction for CNS effects to an external magnetic field exposure is 33 V m^{-1} per T, and for PNS effect 60 V m^{-1} per T. (ICNIRP Publication, 2010)

Table 4: Action levels to electric fields for very low frequency. (Directive 2013/35/EU, 2013)

Frequency Range	Electric field strength low ALs (E) [Vm^{-1}] (RMS)	Electric field strength High ALs (E) [Vm^{-1}] (RMS)
1 ≤ f < 25 Hz	2.0×10^4	2.0×10^4
25 ≤ f < 50 Hz	5.0×10^5 /f	2.0×10^4
50 Hz ≤ f < 1.64 kHz	5.0×10^5 /f	1.0×10^6 /f
1.64 kHz ≤ f < 3 kHz	5.0×10^5 /f	6.1×10^2
3 kHz ≤ f ≤ 10 MHz	1.7×10^2	6.1×10^2

Reference levels have been determined for the exposure conditions where the variation of the electric or magnetic field over the space occupied by the body is relatively small. In most cases, however, the distance to the source of the field is so close that the distribution of the field is non-uniform or localized to a small part of the body. In these cases, the measurement of the maximum field strength in the position of space occupied by the body always results in a safe. (ICNIRP Publication, 2010)

For a very localized source with a distance of a few centimeters from the body, the only realistic option for the exposure assessment is to determine dosimetrically the induced electric field. When the distance exceeds 20 cm, the distribution of the field becomes less localized but is still non-uniform, in which case it is possible to determine the spatial average along the body or part of it. The spatial average should not exceed the reference level. The local exposure may exceed the reference level but with an important provision that the basic restriction shall not be exceeded. It is the task of standardization bodies to give further guidance on the specific exposure situations where the spatial averaging can be applied. (ICNIRP Publication, 2010)

Table 5: Action levels to magnetic fields for very low frequency. (Directive 2013/35/EU, 2013)

Frequency Range	Magnetic flux density low ALs (B) [µT] (RMS)	Magnetic flux density high ALs (B) [µT] (RMS)	Magnetic flux density ALs for exposure of limbs to a localized magnetic field [µT] (RMS)
$1 \le f < 8$ Hz	$2.0 \times 10^5 / f^2$	$3.0 \times 10^5 / f$	$9.0 \times 10^5 / f$
$8 \le f < 25$ Hz	$2.5 \times 10^4 / f$	$3.0 \times 10^5 / f$	$9.0 \times 10^5 / f$
$25 \le f < 300$ Hz	1.0×10^3	$3.0 \times 10^5 / f$	$9.0 \times 10^5 / f$
$300 \le f < 3$ kHz	$3.0 \times 10^5 / f$	$3.0 \times 10^5 / f$	$9.0 \times 10^5 / f$
3 kHz $\le f \le$ 10 MHz	1.0×10^2	1.0×10^2	3.0×10^2

Each of the external electric and magnetic fields induces an electric field component, which adds vectorically in the tissue. In the case of the exposure analysis based on the external electric and magnetic fields, a conservative approach would be to assume that both the electrically and magnetically induced field components attain the maximum value at the same critical point at the same phase. This would imply that the exposures to the external electric and magnetic fields are additive. Such situations, however, are judged to be very infrequent considering the great difference in the distribution of the electrically and magnetically induced electric fields. Table 4 and Table 5 summarize the reference levels for magnetic and electric fields of very low frequency (1 Hz – 10 MHz). (ICNIRP Publication, 2010)

6.3.3 Effects of Very Low Frequency

When people are exposed to LF fields, electric fields and currents are generated inside the body and they can interfere with the body's own electric fields and current flows related to normal biological functioning. In addition, the LF electric field interacts with the surface charge of the body. At low levels, these interactions go mostly unnoticed and do not compromise health. (ICNIRP Publication, 2010)

However, above a certain level of exposure, referred to as threshold, the induced internal fields provoke reversible effects on excitable cells in the body such as a faint light flickering in the periphery of the visual field (phosphenes); electric charge effects on the skin (like what is experienced when you comb your hair, causing your hair to rise); or a stimulation of nerves and muscles experienced as a tingling sensation. These effects occur at different thresholds depending on the frequency of the field. At higher levels, LF causes irreversible cardiovascular effects or tissue burns. Potential health effects associated with long-term low-level exposure have been extensively studied over the last few decades. (ICNIRP Publication, 2010)

Epidemiological studies have suggested that long-term low-level exposure to 50-60 Hz magnetic fields might be associated with an increased risk of childhood leukemia. In addition, no biophysical mechanism has been identified and results from animal and cellular laboratory studies do not support the notion that exposure to 50-60 Hz magnetic fields is a cause of childhood leukemia. Therefore, the currently existing scientific evidence does not lead to the conclusion that a prolonged exposure to LF is a cause of childhood leukemia. Evidence for cancer in adults from LF exposure is very weak. (ICNIRP Publication, 2010)

6.4 High-Frequency Electric and Magnetic Fields (100 kHz – 300 GHz).

High Frequency (HF) is the term used to describe that part of the electromagnetic spectrum comprising the frequency range from 100 kHz to 300 GHz. At high frequency, the electric and the magnetic fields, which together make up the electromagnetic field, are interrelated and considered jointly for measurements. HF field exposure is usually measured in watts per square meter (Wm^{-2}). (ICNIRP Publication, 1998)

HF fields are used in a variety of technologies, most widely for communication purposes (e.g. mobile phones, base stations, Wi-Fi, radio, TV, security devices), and also in medicine (e.g. Magnetic Resonance Imaging (MRI) equipment) and for heating purposes (e.g. microwave ovens).

6.4.1 Exposure Limit

Restrictions on the effects of exposure are based on established health effects and are termed basic restrictions. Depending on frequency, the physical quantities used to specify the basic restrictions on exposure to EMF are current density, Specific Absorption Rate(SAR), and power density. Protection against adverse health effects requires that these basic restrictions are not exceeded. Reference levels of exposure are provided for comparison with measured values of physical quantities; compliance with all reference levels given in these guidelines will ensure compliance with basic restrictions. If measured values are higher than reference levels, it does not necessarily follow that the basic restrictions have been exceeded, but a more detailed analysis is necessary to assess compliance with the basic restrictions. (ICNIRP Publication, 1998)

In the frequency range from a few Hz to 1 kHz, for levels of induced current density above 100 mA m^{-2}, the thresholds for acute changes in central nervous system excitability and other acute effects such as reversal of the visually evoked potential are exceeded. In view of the safety considerations above, it was decided that, for frequencies in the range 4 Hz to 1 kHz, occupational exposure should be limited to fields that induce current densities less than 10 mA m^{-2}, i.e., to use a safety factor of 10. For the general public, an additional factor of 5 is applied, giving a basic exposure restriction of 2 mA m^{-2}. **Below 4 Hz and above 1 kHz, the basic restriction on induced current density increases progressively, corresponding to the increase in the threshold for nerve stimulation for these frequency ranges.** (ICNIRP Publication, 1998)

Established biological and health effects in the frequency range from 10 MHz to a few GHz are consistent with responses to a body temperature rise of more than 1°C. This level of temperature increase results from exposure of individuals under moderate environmental conditions to a whole-body SAR of approximately 4 W kg^{-1} for about 30min. A whole-body average SAR of 0.4 W kg^{-1} has therefore been chosen as the restriction that provides adequate protection for occupational exposure. An additional safety factor of 5 is introduced for exposure of the public, giving an average whole-body SAR limit of 0.08 W kg^{-1}. The lower basic restrictions for exposure of the general public take into account the fact that their age and health status may differ from those of workers. (ICNIRP Publication, 1998)

In the low-frequency range, there are currently few data relating transient currents to health effects. The ICNIRP, therefore, recommends that the restrictions on current densities induced by transient or very short-term peak fields be regarded as instantaneous values which should not be time-averaged. (ICNIRP Publication, 1998)

The basic restrictions for current densities, whole body average SAR, and localized SAR for frequencies between 1 Hz and 10 GHz are presented in Table 6.(See Appendix 1)

Table 6: Basic restriction for human exposure to time varying electric and magnetic field

Exposure characteristics	Frequency range	Current density for head and trunk (mA m^{-2}) (rms)	Whole-body average SAR (W kg^{-1})	Localized SAR (head and trunk) (W kg^{-1})	Localized SAR (limbs) (W kg^{-1})
Occupational exposure	up to 1 Hz	40	—	—	—
	1–4 Hz	40/*f*	—	—	—
	4 Hz–1 kHz	10	—	—	—
	1–100 kHz	*f*/100	—	—	—
	100 kHz–10 MHz	*f*/100	0.4	10	20
	10 MHz–10 GHz	—	0.4	10	20
General public exposure	up to 1 Hz	8	—	—	—
	1–4 Hz	8/*f*	—	—	—
	4 Hz–1 kHz	2	—	—	—
	1–100 kHz	*f*/500	—	—	—
	100 kHz–10 MHz	*f*/500	0.08	2	4
	10 MHz–10 GHz	—	0.08	2	4

[a] Note:

1. *f* is the frequency in hertz.
2. Because of electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm^2 perpendicular to the current direction.
3. For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$ (~1.414). For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$.
4. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate basic restriction.
5. All SAR values are to be averaged over any 6-min period.
6. Localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.
7. For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$. Additionally, for pulsed exposures in the frequency range 0.3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is recommended. This is that the SA should not exceed 10 mJ kg^{-1} for workers and 2mJ kg^{-1} for the general public, averaged over 10 g tissue.

6.4.2 Reference Level for Electric and Magnetic Field

The reference levels or the Action levels are obtained from the basic restrictions by mathematical modeling and from the results of laboratory investigations at specific frequencies. They are given for the condition of maximum coupling of the field to the exposed individual, thereby providing maximum protection. Table 7 summarize the reference levels or the action level for exposure to electric and magnetic fields. (Directive 2013/35/EU, 2013)

Reference levels for exposure of the general public have been obtained from those for occupational exposure by using various factors over the entire frequency range. These factors have been chosen based on effects that are recognized as specific and relevant for the various frequency ranges. The factors follow the basic restrictions over the entire frequency range, and their values correspond to the mathematical relation between the quantities of the basic restrictions and the derived levels as described below:

In the frequency range up to 1 kHz, the general public reference levels for electric fields are one-half of the values set for occupational exposure. The value of 10 kV m^{-1} for a 50-Hz or 8.3 kV m^{-1} for a 60-Hz occupational exposure includes a sufficient safety margin to prevent stimulation effects from contact currents under all possible conditions. Half of this value was chosen for the general public reference levels, i.e., 5 kV m^{-1} for 50 Hz or 4.2 kV m^{-1} for 60 Hz, to prevent adverse indirect effects for more than 90% of exposed individuals. (ICNIRP Publication, 1998)

In the low-frequency range up to 100 kHz, the general public reference levels for magnetic fields are set by a factor of 5 below the values set for occupational exposure. In the frequency range, 100 kHz–10 MHz, the general public reference levels for magnetic fields have been increased compared with the limits given in the 1988 IRPA guideline. In that guideline, the magnetic field strength reference levels were calculated from the electric field strength reference levels by using the far-field formula relating E and H. These reference levels are too conservative, since the magnetic field at frequencies below 10 MHz does not contribute significantly to the risk of shocks, burns, or surface charge effects that form a major basis for limiting occupational exposure to electric fields in that frequency range. (ICNIRP Publication, 1998)

In the high-frequency range, 10 MHz–10 GHz, the general public reference levels for electric and magnetic fields are lower by a factor of 2.2 than those set for occupational exposure. The factor of 2.2 corresponds to the square root of 5, which is the safety factor between the basic restrictions for occupational exposure and those for general public exposure. The square root is used to relate the quantities “field strength” and “power density;” (ICNIRP Publication, 1998)

In the high-frequency range 10–300 GHz, the general public reference levels are defined by the power density, as in the basic restrictions, and are lower by a factor of 5 than the occupational exposure restrictions; (ICNIRP Publication, 1998)

Table 7: Action levels for exposure to electric and magnetic fields. (Directive 2013/35/EU, 2013)

Frequency Range	Electric field strength ALs (E) [Vm-1] (RMS)	Magnetic flux density ALs (B) [μT] (RMS)	Power density ALs(S) [Wm^{-2}]
100 kHz ≤ f < 1 MHz	6.1×10^2	$2.0 \times 10^6/f$	-
1 ≤ f < 10 MHz	$6.1 \times 10^8/f$	$2.0 \times 10^6/f$	-
10 ≤ f < 400 MHz	61	0.2	-
400 MHz ≤ f < 2 GHz	$3 \times 10^{-3}/f^{0.5}$	$1.0 \times 10^{-5}/f^{0.5}$	-
2 ≤ f < 6 GHz	1.4×10^2	4.5×10^{-1}	-
6 ≤ f < 300 GHz	1.4×10^2	4.5×10^{-1}	50

6.4.3 Effects of High Frequency

The critical effect of HF exposure relevant to human health and safety is heating of exposed tissue. HF fields can penetrate into the body (the higher the frequency, the lower the penetration depth) and cause vibration of charged or polar molecules inside. This results in friction and thus heating could be observed. (ICNIRP Publication, 1998)

The body can accommodate a small increase in heat, in a similar way that excess body heat is dissipated when performing the sporting activity. This is because the human body has a strong ability to regulate its internal temperature. However, above a certain level depending on the duration of exposure, HF exposure and the accompanying temperature rise can provoke serious health effects, such as heatstroke and tissue damage (burns). (ICNIRP Publication, 1998)

Acute and long-term effects of HF exposure below the thermal threshold have been studied extensively without showing any conclusive evidence of adverse health effects.
A considerable amount of research has been conducted on the relationship between HF fields and health outcomes such as headaches, concentration difficulty, sleep quality, cognitive function, cardiovascular effects, etc**. The only consistently observed finding is a small effect on brain activity measured by electroencephalography (EEG).** The biological implication of these small changes is, however, unclear. For example, they have not been shown to affect sleep quality or be associated with any other adverse effects. (ICNIRP Publication, 1998)
Extensive research has been undertaken in relation to exposure to HF fields used specifically in the mobile telephone. Among all of this research, the risk of tumours in close proximity to the ear where the phone is held, e.g. brain tumours, has been the focus of numerous epidemiological studies. A few of these epidemiological studies have reported a slight statistical increase in the risk of some brain tumours for the small group of long-term and heavy mobile phone users. Several studies have not reported any increase in brain tumours with mobile phone use. Also, experimental studies on animals and cells have failed to confirm the findings of the epidemiological studies, and there is no biophysical mechanism that could explain carcinogenicity at such low exposure levels. In addition, the increased risk observed in some of the epidemiological studies is inconsistent with the stable frequency of occurrence of these cancers in the population. That is an important consideration, given the widespread and significant increase in the use of mobile phones in the general population during the last few decades. (ICNIRP Publication, 1998)

The overall evaluation of all the research on HF fields leads to the conclusion that HF exposure below the thermal threshold is unlikely to be associated with adverse health effects. (ICNIRP Publication, 1998)

7 Conclusion

In the present scenario, one of the major problem in this digital world would be Electromagnetic pollution. The high-level electromagnetic disturbances can create a problem to the normal operating electrical devices which are operating in a common electromagnetic environment. All the electronics devices should be electromagnetically compatible with other electronic devices.

To get rid of those health hazards, the electrical system and the electronics equipment should have enough consideration for electromagnetic compatibility. The manufacturer of electronics equipment should have EMC technical reports stating its standardization and regulation as per the respective countries. (Directive 2014/30/EU , 2014)

A number of other adverse health effects have been studied for possible association with Extremely Low Frequency (ELF) magnetic field (above 0.3 to 0.4µT) exposure. These include other childhood cancers, cancers in adults, depression, suicide, cardiovascular disorders, developmental disorders, immunological modifications, neurobehavioral effects and neurodegenerative disease. The WHO Task Group concluded that scientific evidence supporting an association between ELF magnetic field exposure and these health effects is much weaker than for childhood leukemia.

In some instances, (i.e. for cardiovascular disease or breast cancer) the evidence suggests that these fields do not cause them. Government and industry should monitor science and promote research programs to further reduce the uncertainty of the scientific evidence on the health effects of ELF field exposure. Through the ELF risk assessment process, gaps in knowledge have been identified and these form the basis of a new research agenda. Thus, more research should be made to get a precise conclusion. (World Health Organization, 2007)

At the end, this is a general report and could be used for different purposes. The report has clearly mentioned the exposure limit, reference level and adverse effect on human health with various level of frequencies, as today's equipment uses a different level of frequencies. Studying this report could help any individual know easily the effect of the frequency that he is using and could be reviewed whether it is safe for human or not.

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Appendix 1:

1. Basic Restriction for human exposure to time-varying electric field. (ICNIRP Publication, 1998)

Exposure characteristics	Frequency range	Current density for head and trunk (mA m^{-2}) (rms)	Whole-body average SAR (W kg^{-1})	Localized SAR (head and trunk) (W kg^{-1})	Localized SAR (limbs) (W kg^{-1})
Occupational exposure	up to 1 Hz	40	—	—	—
	1–4 Hz	40/f	—	—	—
	4 Hz–1 kHz	10	—	—	—
	1–100 kHz	f/100	—	—	—
	100 kHz–10 MHz	f/100	0.4	10	20
	10 MHz–10 GHz	—	0.4	10	20
General public exposure	up to 1 Hz	8	—	—	—
	1–4 Hz	8/f	—	—	—
	4 Hz–1 kHz	2	—	—	—
	1–100 kHz	f/500	—	—	—
	100 kHz–10 MHz	f/500	0.08	2	4
	10 MHz–10 GHz	—	0.08	2	4

[a] Note:

1. f is the frequency in hertz.
2. Because of electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm^2 perpendicular to the current direction.
3. For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$ ($\sim$1.414). For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$.
4. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate basic restriction.
5. All SAR values are to be averaged over any 6-min period.
6. Localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.
7. For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$. Additionally, for pulsed exposures in the frequency range 0.3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is recommended. This is that the SA should not exceed 10 mJ kg^{-1} for workers and 2mJ kg^{-1} for the general public, averaged over 10 g tissue.

2. Reference levels for occupational exposure of electric and magnetic field. (ICNIRP Publication, 1998)

Frequency range	E-field strength ($V m^{-1}$)	H-field strength ($A m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W m^{-2}$)
up to 1 Hz	—	1.63×10^5	2×10^5	—
1–8 Hz	20,000	$1.63 \times 10^5/f^2$	$2 \times 10^5/f^2$	—
8–25 Hz	20,000	$2 \times 10^4/f$	$2.5 \times 10^4/f$	—
0.025–0.82 kHz	$500/f$	$20/f$	$25/f$	—
0.82–65 kHz	610	24.4	30.7	—
0.065–1 MHz	610	$1.6/f$	$2.0/f$	—
1–10 MHz	$610/f$	$1.6/f$	$2.0/f$	—
10–400 MHz	61	0.16	0.2	10
400–2,000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.01f^{1/2}$	$f/40$
2–300 GHz	137	0.36	0.45	50

[a] Note:

1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width, does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (f in GHz).
7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment.

3. Reference levels for general public exposure of electric and magnetic field. (ICNIRP Publication, 1998)

Frequency range	E-field strength ($V\ m^{-1}$)	H-field strength ($A\ m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W\ m^{-2}$)
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	$4,000/f$	$5,000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

[a] Note:

1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (f in GHz).
7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields. perception of surface electric charges will not occur at field strengths less than 25 kVm^{-1}. Spark discharges causing stress or annoyance should be avoided.

Appendix 2:

1. Typical magnetic field strength of household appliances at various distances. Normal operating distances are given in bold. (Federal office for radiation safety, Germany 1999)

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**

With most household appliances the magnetic field strength at a distance of 30 cm is well below the guideline limit for the general public of 100 µT.

2. Summary of the ICNIRP exposure guidelines. (ICNIRP, EMF Guidelines, Health Physics 74,494-522 (1998)

Summary of the ICNIRP exposure guidelines

	European power frequency		Mobile phone base station frequency		Microwave oven frequency
Frequency	50 Hz	50 Hz	900 MHz	1.8 GHz	2.45 GHz
	Electric field (V/m)	Magnetic field (μT)	Power density (W/m^2)	Power density (W/m^2)	Power density (W/m^2)
Public exposure limits	5 000	100	4.5	9	10
Occupational exposure limits	10 000	500	22.5	45	

3. Public Exposure with Electric and Magnetic Field (WHO Regional office for Europe)

Source	Typical maximum public exposure	
	Electric field (V/m)	Magnetic flux density (μT)
Natural fields	200	70 (Earth's magnetic field)
Mains power (in homes not close to power lines)	100	0.2
Mains power (beneath large power lines)	10 000	20
Electric trains and trams	300	50
TV and computer screens (at operator position)	10	0.7
	Typical maximum public exposure (W/m^2)	
TV and radio transmitters	0.1	
Mobile phone base stations	0.1	
Radars	0.2	
Microwave ovens	0.5	