A Study of the Effects of Electromagnetic Fields on Digital Television Antenna Radiation: A Simulation and Evaluation of Exposure

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***Abstract*—Electromagnetic compatibility is the ability of systems or equipment to be tested in the intended environment through levels of efficiency without degradation caused by electromagnetic interactions. Compliance with safety limits requires tests to measure the device when operated at w maximum power maintained over an average period of time. However, the average transmitted power of many of these devices depends on a range of system parameters, such as power control and others. Several agencies now require these devices to be subjected to safety limit tests, but are faced with the problem of a lack of standardized assessment procedures. This is a cause of anxiety among agencies, industry and consumers. The objective of this study is to examine procedures that can determine the maximum permissible exposure to radiation and that are scientifically and technically sound. Compliance with standards can be investigated on the basis of Specific Absorption Rate (SAR) measurements and derived quantities, i.e, the electric field and magnetic field. In this study, compliance with the electric field was carried out through the development of simulations, to aid in the evaluation of the exposure of populations that currently are (or will be) the subject of digital TV services in the frequency range of 599 MHz.**

Keywords-electromagnetic compatibility; simulation; method of moments; antenna array

I. INTRODUCTION

Electromagnetic fields naturally come from three main sources: the sun (130 mW/cm^2 at all frequencies), storm activities (electric fields in the range of many volts per meter) and the Earth's magnetic field (in the order of 40 A/m). In the last hundred years, radiofrequency fields generated by man, with much higher intensities and with a very different spectral power distribution, have changed these natural electromagnetic fields; and as a result they are now under study. The radiofrequency fields are classified as non-ionizing radiation because the frequency is too low for the photon energy to ionize atoms but at a sufficiently high power density to heat body tissue.

The general public has been exposed to these electromagnetic fields since the mobile phone market is one of the fastest growing services in the telecommunications industry. Owing to the damage that can be caused by Non-Ionizing Radiation (NIR) emitted by base stations, the use of mobile phone stations has begun to be questioned and raised serious concerns regarding the adverse effects of radiation. This problem is not limited to mobile phones, but any antenna in the range of non- ionizing radiation.

Since 1974, many countries have conducted research to enable them to lay down safety standards for protection. The Environmental Health Division of the World Health Organization (WHO) and International Radiation Protection Association/ International Non-Ionizing Radiation Commitee (IRPA/INIRC) jointly drew up a number of reports that form a part of the program of the WHO criteria for Environmental Health, sponsored by the United Nations Environmental Programme (UNEP). Each report includes an overview of physical and technical features such as measurement, instrumentation and sources of NIR applications. These provide criteria for fixing the exposure limits in scientific experiments and adopting procedures with the NIR data. The guidelines complied with the International Commission on Non-Ionizing Radiation Protection (ICNIRP), set up in 1994, and stipulated the limits of exposure to electromagnetic fields at frequencies between 9 kHz and 300 GHz. In Brazil, Resolution No. 303/2002 of the National Telecommunications Agency (ANATEL) National Council adopted the ICNIRP guidelines for limiting exposure to electromagnetic fields [1].

In [2], an estimate was made of the probable source of maximum exposure to electromagnetic fields from a radio-communication station, based only on information about the height of the antenna, half-power angle and tilt. In [3], there is an evaluation of the levels of non-ionizing radiation subjected to by people inhabiting an area adjacent to the Radio Base Station (RBS). These measurements show the relationship between power versus distance used to calculate the far field (the electric field in the region). This field is used to calculate the levels of exposure to non-ionizing radiation that the general public is exposed to. In [4], a computational method is proposed for predicting electromagnetic wave propagation in the UHF range using the Method of Moments (MoM). The authors employed a prediction model. This also estimates the protection zone from the frequency and feed power values. In [5] and [6], there is a study of the radiation level from mobile telephony base-station antennas using electromagnetic (EM) field simulation and making comparisons with the on-site EM field measurement. In [7], a minimum distance requirement based on a SAR simulation is proposed for mobile base station antennas, and in [8], the impact of Wi-Fi access points is investigated to determine electromagnetic field exposure. The evaluations were carried out through measurements and the simulation through a ray tracing method. Stratakis et al. [9] evaluated the authors evaluated the electromagnetic field exposure, using measurements generated by Wimax Base Stations.

In this study, methods were employed to assess the compliance of wireless systems with the established limits of electromagnetic exposure in humans. A method is proposed for numerical analysis. Exposure assessments of wireless systems, under a limited set of operating conditions, were performed to estimate the maximum levels of the electric field.

In this paper, a system is proposed and implemented that involves the calculation of the limits of human exposure, by assessing the electric field that is simulated by antenna arrays in the UHF Range. The electric field was obtained by numerical simulation through the software implementation of the Method of Moments, expanded from the dipole antenna (as described in [4]) to the antenna array. The results obtained can aid the regulatory agencies by providing information about the location, antenna heights or Effective Isotropic Radiated Power (EIRP) irradiated by these antennas.

This work is structured as follows: Section 2 will address the question of exposure levels. In Section 3, the tool developed to assess exposure is described. In Section 4, the results are shown. Finally, Section 5 summarizes the conclusions of the proposed work.

II. Exposure Levels

The board of directors of the ANATEL Council as its meeting of July 15, 1999, decided to adopt, (as a provisional measure), the radiation limits proposed by the ICNIRP. These were based on an evaluative study of human exposure to radiofrequency electromagnetic fields from transmission stations of telecommunications services. The purpose of the ANATEL regulatory requirements is to set limits and define the evaluation methods and procedures that must be followed by radio stations when granted licences. In the case of human exposure to electric, magnetic and electromagnetic fields radio frequencies have to be in the range of 9 kHz to 300 GHz [4].

The parameters used to define exposure limits are the electric field, magnetic field and plane-wave equivalent power density, subject to basic restrictions. The basic restrictions are based on the health risks caused by exposure to electric fields, or magnetic and electromagnetic variables in time. Depending on the frequency of the field, the physical quantities used to specify these restrictions are current density (J), SAR and power density (S).

These limits correspond to those of the ICNIRP guidelines and have been established by employing quantities that can be more easily measured or calculated than the basic restrictions.

Table I shows the exposure limits of the general public to electromagnetic fields in a range of frequencies between 9 KHz and 300 GHz.

TABLE I. LIMITS OF THE GENERAL PUBLIC TO ELECTROMAGNETIC FIELDS IN A RANGE OF FREQUENCIES BETWEEN 9 KHZ AND 300 GHZ [10]

Radio Frequency Range	**E Field Intensity (V/m)**	**H Range Intensity (A/m)**	**Power Density Seq (W/m^2)**
9 KHz to 65 KHz	87	5	_____
0.065 KHz to 1 MHz	87	0.73 / f	_____
1 MHz to 10 MHz	$87 / f^{1/2}$	0.73 / f	_____
10 MHz to 400 MHz	28	0.073	2
400 MHz to 2000 MHz	$1.375 f^{1/2}$	$0.0037 f^{1/2}$	f / 200
2 GHz to 300 GHz	61	0.16	10

III. Tool for Modelling of Electromagnetic Waves

Guerreiro et al. [4] proposed a tool that employed the method of moments to model a radiated field with a dipole antenna.

This study used a customization of a Matlab ® package described in [11][12] and extended the work [4] to predict the irradiation of an array of antennas. It is necessary to rely on Rao-Wilton-Glisson (RWG) basic functions [11], the electric field integral equation, and the feedingedge model of the underlying MoM code [11] to stimulate radiation and the scattering of basic Radiofrequency (RF) waves, wireless communication antennas and microwave structures.

The customization implemented in this work is able to calculate the exposure level in a diagram based on the voltage signal in the array antenna feed, the antenna structure and the operation frequency, as input of the updated software. The flowchart of the code execution and the new software proposed, is shown in Fig. 1.

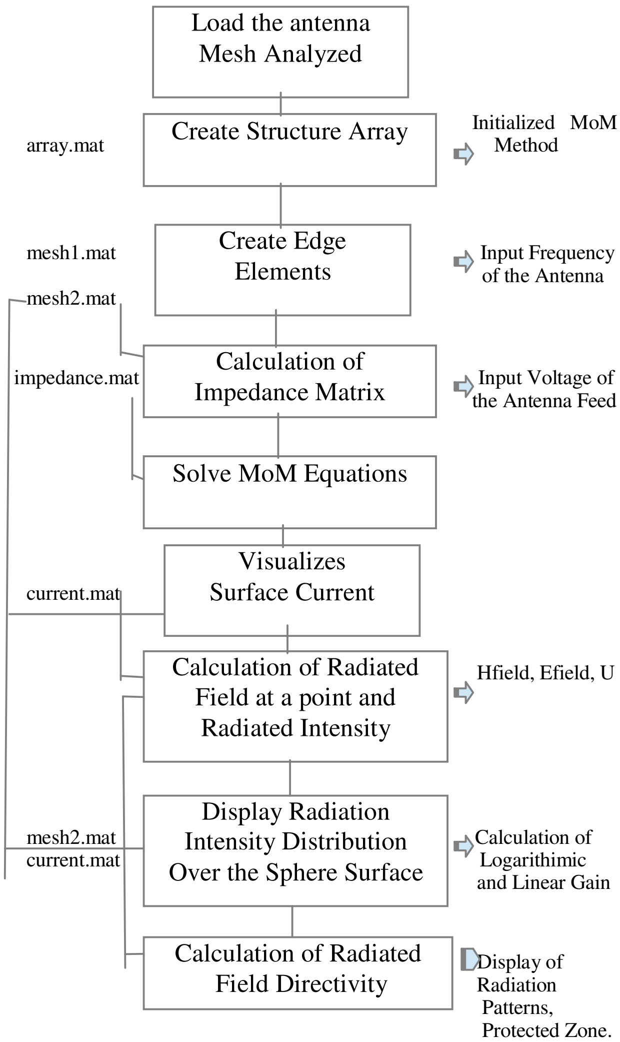

Figure 1. Flowchart of code execution sequence, adapted from [4], [11] and [12].

In the box 1, the antenna mesh is the input of the box 2 where the software builds the structure of the array and generates the file array.mat. This file, array.mat, is the input of the third box and where the edge elements are created generating the file mesh2.mat. The fourth box is responsible to calculate the impedance matrix and saving the file as impedance.mat. This file, impedance.mat, is the input of the MoM solver, after the surface current can be plotted using the sixth box and a file current.mat is generated. This last file is the input of the seventh box which calculates the radiated field in a single point. The box eighth and nineth are responsible to display the radiated field over a sphere surface and to calculate the radiated field directivity. Our customization was made in the box seventh to nineth where the evaluation of safe field according to ANATEL´s rules was implemented and finally a determination of the protected zone around the antenna can be defined according to the results described in the next section and showed in Fig. 2.

This tool mainly contributed to calculate the electric field in a practical way, aiding other possible works which needs this metric to develop proposed reseachers models.

Moreover, despite in [4], where the electric field value was calculated to dipole antenna. At this work the electric field is calculated to antenna array. This way, adding a new realistic possibility to attend wireless communications in the UHF range as digital TV.

IV. Results

An array of antennas was used for the evaluation operating at a frequency of 599 MHz, horizontal polarization, with feed power of 1,333 kV, 0.288 m long and 0.5 cm wide. The antenna had a height of 125 meters. The antenna array used was of the broadside type with 8 elements and 0.25 cm spacing between the elements. These settings were adjusted in the multilinear.m file, dipolo599.mat, rwg3.m, rwg4.m and efield3.m [11].

In the MATLAB code efield1.m [11], the radiated scattered/field is calculated at a point that is outside the antenna surface. This corresponds to Box Seven in Fig. 1. The Efield1.m code was modified to discover where the electric field is considered to be non-compliant (larger than the minimum field permitted by the ANATEL regulations) and where it is considered to be safe.

In the code efield3.m [11], a customization was carried out to meet the objectives of this work, i.e., to trace a diagram exposure level around the antenna array in accordance with ANATEL regulations. Thus, a loop that can vary the radius of 1 meter to any value specified by the decision maker, was added to the code. The results of the electric field, the corresponding radius, and angle were stored for further analysis and are shown in Fig. 2.

The straight line described in the caption in Fig. 2 is the protection zone; this defines the contour of the protection zone. Electric field values below the ANATEL reference-point are represented by the plus (‘+’) signal and values above the limit of ANATEL are represented by a dot (‘.’) signal. In Fig. 2, it can be seen that the lowest height of a building near the antenna should be approximately 120 meters and the antenna distance should be about 20 meters. At a distance of about 40 meters from the antenna, any building could be built at about 125 meters of height, as shown in Fig. 2. ANATEL defines a range of 599MHz, in accordance with Table I, which is an exposure below 33.65 V/m.

It was confirmed that the MoM gives feasible results as shown in [13] even when it is employed to predict an array of antennas.

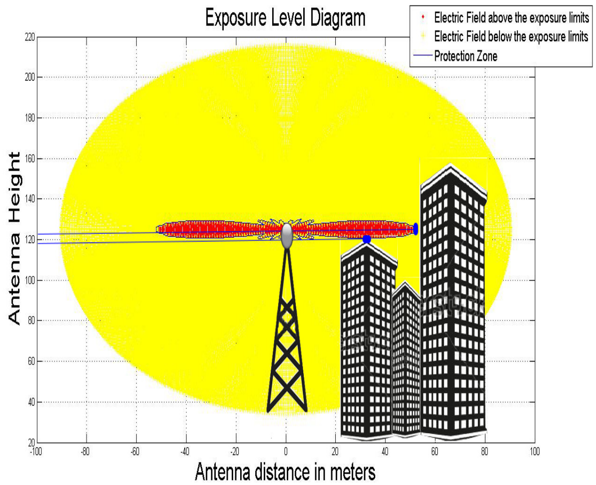

Figure 2. Diagram of Exposure Levels

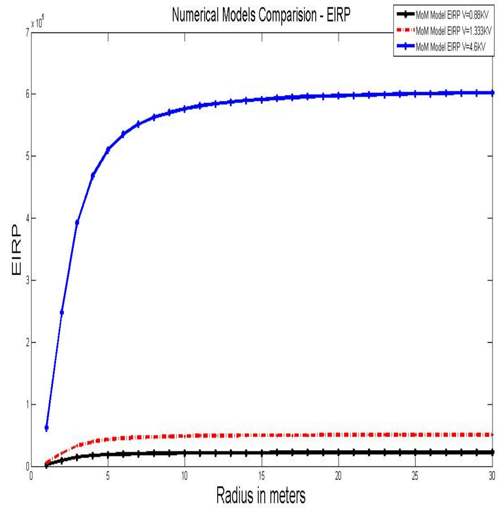

Figure 3. Values of EIRP versus Voltage feedback

In Fig. 3, there are three curves and the data are simulated to 125 meters in height. This chart shows the EIRP, (effective isotropic radiated power in Watts) and was calculated on the basis of different voltage feedback (0.88 kV, 1.333 kV and 4.6 kV) of the antenna array. It demonstrated that with a high voltage feed of 4.6 kV, the EIRP values are very high. This should give a warning to the decision makers. The two other values used in the simulation showed low values of EIRP, (less than 50 kW).

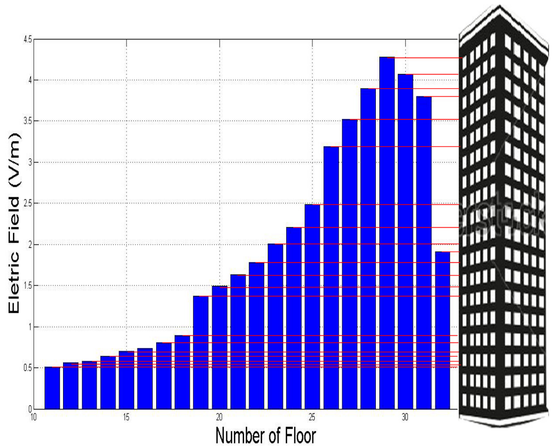

Figure 4. Electric field simulated on each floor [*In chart > Number of Floors]

The most interesting analysis is found in Fig. 4, where the electric field is simulated on each floor of a building that is higher than 125 meters and at a distance of 66 meters from the antenna array. The simulation showed the electric field increased as far as the main lobe of the antenna array and then decreased. The maximum value of the electric field was 4.28 V/m at floor number 29. This situation is similar to what happens in real life where buildings are often built near to the antenna locations or vice-versa.

V. CONCLUSION

This paper outlines the results of the effects of electromagnetic fields generated by antenna arrays. An antenna array has the advantage of providing a high gain for long distances, which means it can be used for emerging applications. One of its applications is in digital televisions and mobile devices that use smart antennas.

In this study, the effects are predicted by calculating antenna patterns using MoM, if the antenna construction is known and using the proposed model to generate the protection zone (as shown in Fig. 2). The tool also generates numerical simulations of the EIRP versus voltage feedback, as shown in Fig. 3 and finally, from a specific distance from the antenna location, it generates an electric field of any height to predict the exposure level of buildings surrounding the antenna.

The main problem in a practical application of complex computational techniques (when compared with the findings of this study) is that ray tracing, for example, requires the geometry to be specified in detail. On the othe hand, in practice, the obstacle to using even simple two-ray models, is a lack of adequate information about the antenna and the exposure level to the environment. This means that the available data about the terrain may have limited resolution. Another example is when the antenna pattern provided by the manufacturer is valid for the far-field region. Thus, it is believed that this study has made a feasible contribution to this field of studies.

The research contributions of the paper is a practical tool to calculate electric field to predict the protection zone around the antenna arrays, aiding the researches without any complexity technique as ray tracing or too simplicity as two ray model, providing the researchers in this area with predicted electric fields values to aid ou to validate their works in electromagnetic compatibility and so on.

Moreover, despite the scientific uncertainty surrounding this issue and the absence of tools and practical procedures, this research has sought to continue to assist public decision making by making a calculation of the exposure levels of NIR emitted by the antennas that will be designed. The next stage is to perform signal strength measurements to confirm the validity of the developed tool.

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