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Electromagnetic Field Exposure Assessment in a Multi Source Telecommunication Environment

Application to Nonoccupational Exposure in Public Spaces

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Abstract
RF-EMF exposure assessment carried out in an observatory open for general public visits, where there are multiple RF sources in the surrounding area. Fields at some points of interest have exceeded the ICNIRP exposure limits for the general public and, to comply with normative limits, relevant stations reduced their radiated power. Nevertheless, the total electric field strength in the vicinity of the observatory's metallic parapet still exceeds exposure limits due to re-radiation. Thus, the main broadcast stations reduced even more their transmitted power to comply with the regulatory limits throughout the observatory area. A detailed evaluation is carried out close to metallic objects to assess the re-radiation phenomenon. Additionally, laboratory experiments were carried out to confirm the influence of re-radiation from the metallic parapet.

Keywords Nonoccupational exposure · EMF limits · Open site measurement

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1 Introduction

Past, present and future technologies that are based on intentional emission of electromagnetic fields are (and will be) pervasive in human life. This can be verified by the dynamic nature of the electromagnetic environment in the last decades and the constant development of communication technologies. The number of humans with constant interaction with man-made electromagnetic fields (EMF) grows every year. In 2017, there were more than 4.3 billion cell phone subscriptions worldwide and mobile-broadband subscriptions have grown more than 20% annually in the last 5 years [1].

On the other hand, there is widespread public concern regarding the potential hazards or indirect risks to human health due to EMF radiation. There are several recent studies on possible health effects due to EMF ranging from low to high frequencies [2–4]. Many studies claim that EMF exposure can cause serious health effects in humans. However, some of them suffer from conflicting results and methodological limitations [5]. The possible growth of EMF energy in the environment due to the constant increase in number of devices and new technologies that use RF such as the Internet of Things (IoT) requires constant verification of the electromagnetic spectrum, by means of spectrum monitoring and EMF assessment. The main concern is nonoccupational exposure (also known as general public exposure) from transmitters, including radio, television, microwave links, and mobile communications where high-power broadcasting transmitters are the most relevant sources.

In this paper, it is presented the assessment of the EMF exposure carried out in a complex and realistic environment: an observatory which can be visited by the general public located close to a multi sources telecommunications environment (broadcasting, radio communication, point-to-point fixed systems, etc). Total exposure has been evaluated by electric and magnetic measurements, following international standards [6, 7]. The main goal is to discuss nonoccupational human exposure at multi EMF sources in a public area and to develop a framework for EMF assessment using measurements.

2 Standards for Exposure to Electromagnetic Fields

According to [8] it is possible to differentiate between occupational and general public (nonoccupational) exposure. The occupationally exposed population consists of adults who are generally exposed under known conditions and are trained to be aware of potential risks and to take appropriate precautions. By contrast, the general public comprises individuals of all ages and of varying health status, and may include particularly susceptible groups or individuals [8]. Aspects regarding the occupational and nonoccupational exposure to low frequency and radiofrequency (RF) electromagnetic fields were presented in [9].

In this work, the framework adopted to investigate the nonoccupational EMF exposure assessment in a public space with multiple sources is composed of the following basic tasks:

(A) Assignments of exposure limits that are safe for people, as established by: (a) The International Commission on Non-Ionizing radiation protection (ICNIRP) [8], endorsed by World Health Organization (WHO); (b) The International Committee on Electromagnetic Safety (ICES) of the IEEE [10]; and (c) National regulatory authorities.

(B) Standards for evaluation and measurement of exposure levels, provided by: (a) The International Electrotechnical Commission (IEC) 62xxx series [11]; (b) The European Committee for Electrotechnical Standardization (CENELEC) EN50xxx series; (c) The European Cooperation in Science and Technology (COST); and (d) National regulatory authorities, when these exist.

(C) On-site and laboratory measurements and subsequent analysis according to standards [10, 12].

The committees described in (A), based on scientifically proven biophysical and biological interactions, derive exposure limit values (ELV) regarding human exposure to EMF. These ELV are issued in guidelines that are revised every few years [8, 10]. It is important to note that the exposure limits can be different in different countries. Data concerning exposure limits by countries can be found on the WHOs database [13].

Considering (B), COST 281 is an European action for cooperation in the field of science and technological research on biological effects of electromagnetic fields from emerging technologies, in particular from mobile communication and information technologies. In [14] is possible to find the following data:

1. Available data for use by various decision makers involved in risk management of EMF;
2. A basis for risk communication efforts related to emerging technologies;
3. EMF and possible health risks, and
4. Data on EMF exposures related to emerging technologies on a European level.

In addition, IEC/CENELEC created the technical committees TC106 [11]. TC106 tasks includes: characterization of the electromagnetic environments with regard to human exposure; measurement methods, instrumentation and procedures; calculation methods; assessment methods for the exposure produced by specific sources (this task is not carried out by specific product committees); basic standards for other sources; assessment of uncertainties. It covers the whole frequency range from 0 Hz to 300 GHz and applies to basic restrictions and reference levels.

Measurements performed in (C) satisfy the standards in open area and laboratory environments, respectively. Many countries, including Brazil impose limits on human exposure to electric, magnetic and electromagnetic fields according to ICNIRP recommendations. However, some countries are adopting more restrictive limits. For instance, Table 1 [13] shows the comparison between those limits for different countries at 900 MHz.

Recent publications from academia and the private sector relating to health issues and EMF exposure emphasize the importance of a framework for assessing EMF levels.

Table 1 Exposure limits to 900 MHz radio-frequency fields [13]

	Brazil	Canada	Germany	Italy	Japan	US
Electric field (V/m)	41.25	32.1[a]	41.252	20[b]	47.55	47.63[c]

[a]The formula for calculating E-field reference levels at frequencies between 300 MHz and 6 GHz is 3.142 f (exp 0.3417)—where f is the frequency in MHz

[b]The exposure limit is 20 V/m. Moreover, in homes, schools, playgrounds and places where people may stay for longer than 4 h, an 'attention value' of 6 V/m is applied and averaged over any 24 h period

[c]Averaging time is 30 min

- The Japan Society for Occupational Health (JSOH) recommends occupational exposure limits (OELs 2016–2017) as reference values for preventing adverse health effects in workers caused by occupational exposure to time-varying electric, magnetic and electromagnetic fields and ultraviolet and ionizing radiation [2];
- Electric and Magnetic Fields and Health: Review of the Scientific Research from March 2012 to December 2016 [3], that brings conclusions of weight-of-evidence reviews of EMF and health and case studies related to childhood leukemia, childhood brain cancer, adult cancers, in vivo studies of carcinogenesis, reproductive and developmental effects and neurogenerative diseases.
- The National Cancer Institute (NCI) published the Electromagnetic Fields Fact-Sheet [4], about cell phone base stations and they concluded that exposures among maintenance workers vary depending on their tasks and the type of antenna. Cumulative exposures of such workers are very difficult to estimate.

Furthermore, there are non-industry versus industry studies that show vast differences in the harmful effects of microwave radiation. According to [15], microwave technology industrial professional societies state emphatically that there is no such effect as non-thermal radiation that may cause adverse health effects. In addition, this radiation could not contribute to and/or cause electromagnetic hypersensitivity (EHS) or what physicians call idiopathic environmental intolerance (IEI) in sensitive people around the world [15].

The role of standardization committees as ITU [1] remain as providing science based EMF standards to ensure appropriate level of health protection to the society. As stated before, there are several different standards concerning human exposure assessment. Some can be considered general. Others product oriented. However, real life situations can present several sources of radiation operating simultaneously. Considering this, guidance and research on the assessment of nonoccupation human exposure at multi source environment is still required.

The effect of scattering and/or re-radiation due to parasitic (specially metal) objects is well described in [6]. It is drawn some general conclusions by [6]:

- Potential hazards to personnel due to passive re-radiators are reduced or enhanced with respect to exposure to plane waves of equal maximum normalized eld strength.
- Caution should be exercised when interpreting so-called, localized hot spots caused by re-radiating objects because the amount of energy that may be coupled to an individual contacting the re-radiator may be very small, despite the existence of relatively high-surface eld strengths.

The re-radiation effects and its influence on the EMF assessment are being studied at ITU-T Study Group 5 (SG5) under the scope of K.61 Recommendation [7]. The Case Study presented in this paper was used as a Brazilian contribution presented in the SG5 in 2017.

3 The Case Study of an Observatory

In the present work, the EMF exposure in a complex and realistic environment is assessed. The site is an observatory, located at Boa Vista Hill, in Joinville, Brazil. The observatory gazebo is surrounded by ungrounded metallic parapets and a massive concrete floor, where the general public can visit at any time. Thus, the nonoccupational exposure limits should be respected at this location. At Boa Vista Hill, there are several sources of broadcasting and telecommunication services including VHF, UHF and several microwave bands. The distances between the most relevant sources (antennas) and the gazebo are about 19–32 m.

On site measurements were performed using time-averaging, with 6 min averaging for the E and H fields in the frequency range 100 kHz–1 GHz (up to 3 GHz for the E field), according to international recommendations [8, 10].

Given the complexity of the case study, additional measurements were carried out in a controlled environment (laboratory with anechoic chamber). Laboratory measurements are useful since re-radiation from a nearby metallic structure can give rise to excessive field strengths. The time-variant reradiated fields can generate constructive or destructive interferences in the measured field at a given point. This feature can be difficult to control in multi source environment.

In the literature, it is possible to find different definitions for the term re-radiation. In [16], it is defined as the field originating from interconnected networks. A different definition can be found in [17] where the reradiated field is described as the total field created by the interconnection, scattering or coupling between antennas. A recent study applied to re-radiation in power lines demonstrated that the impedance matrix is determined by the structural characteristics of the power line [18]. The IEEE provides a set of procedures to be followed to cope with re-radiation of AM broadcast signals from power lines and other large metallic structures [19].

According to [10], reradiated field is an electromagnetic field resulting from currents induced in a secondary, predominantly conducting, object by electromagnetic waves incident on that object from one or more primary radiating structures or antennas. Reradiated fields are sometimes called reflected or more correctly scattered fields. The scattering object is sometimes called a re-radiator or secondary radiator [10].

3.1 Measurements Setup

Evaluations were performed following international standards [7, 10, 12]. These recommendations provide guidance on measurement methods that can be used to achieve a compliance assessment. They also provide guidance on the selection of numerical methods suitable for exposure prediction in various situations. The instruments that were used are:

1. Laboratory Tests: Electric Field Probe 100 kHz–6 GHz User-Selectable X, Y, Z Axes (Amplifier Research Model FL7006) and NBM-520 Broadband Field Meter with electric field probe EF 03991 (100 kHz–3 GHz);
2. Outside Tests: NBM-520 Broadband Field Meter with electric field probe EF 03991 (100 kHz–3 GHz) and EMR-300 Broadband Field Meter with magnetic field probe Type 10C (27 MHz–1 GHz);
3. Sensor positions: Ranging from 90 to 1080 mm from the parapet located in the worst affected region (with higher field strength).

Outdoors and laboratory measurements are described next.

3.2 Outdoor Tests

A preliminary analysis was made using both, broadband and selective instrument (narrow band: probe with spectrum analyzer). However, in order to guarantee the compliance of limits on both the electric and magnetic fields, the use of broadband equipment was the most appropriate, since it was identified the presence of a re-radiator and so therefore a near field region. In addition, since the electric field was relatively high, the use of narrow band instruments—the spectrum analyzer (which can be used in conjunction with a laptop) could present an electromagnetic compatibility problem. On the other hand, the detection using broadband instrument is performed by diode, thermo coupled or compensated diode, that measures the sum of power density contributions from all the sources operating within the frequency range of the field probe and the immunity to radiated electric field is up to 200 V/m.

Several measurements were taken and repeated and some discarded or eliminated, for example, when people were circulating in the test space. Most of the measurements were carried out at dawn without visitors at the observatory.

As stated before, there are several sources of broadcasting and telecommunication services in the VHF, UHF and microwave bands near the observatory. However, it was verified that more than 90% of the total power density contribution came from only 5 sources, all in the VHF band: one analog TV and four FM radios. There are no AM sources near the observatory.

The instrument used for electric field evaluation measures all sources in the range from 100 kHz to 6 GHz. When there are multiple sources (as in this case), the error may increase as anticipated by the equipment's manufacturer [20]. However, it was not observed a significant error in the instrument related to the multiple carriers, as evidenced in tests done by selectively switching off transmitters.

To analyze the near-to-far-field transition zone, a broadband electric field meter was gradually moved away from the metallic parapet, as shown in the Fig. 1. According to [10], measurements should be made at a distance no closer than three probe-diameters between the center of the probe and any object. Thus, the measurements were carried out from 90 mm, since the size of the probe used is 30 mm. Based on these measurements; it was obtained evidence of near-field existence in the proximity of the parapets, due to re-radiation from the metallic structure (Fig. 2).

Fig. 1 Near-field measurements at the Observatory

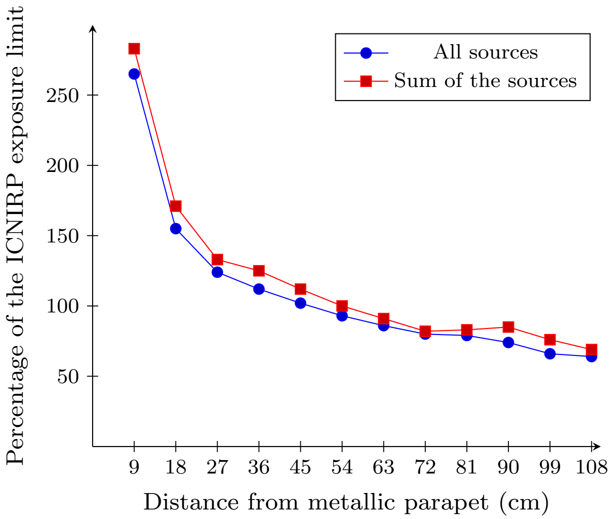

Fig. 2 Comparison between exposure measurement (total and sum of contributions) considering limit within frequencies from 100 to 400 MHz

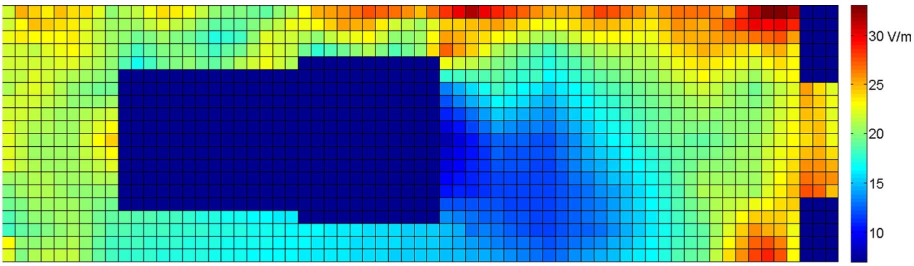

Fig. 3 Electric field measurement map with main sources operating with 25% of the licensed power

Table 2 Wave impedance as a function of distance from parapet

Dist. (cm)	27	54	81	108	135	162	189	216
$\|E/H\|\Omega$	423	432	472	462	455	417	394	380

Even with the reduction of the main sources to 25% of the authorized power, it was observed some hot spots, although the spatial averaging of the fields was kept below the ICNIRP limit of 28 V/m [8]. Figure 3 illustrates a view of the spatial averaging method. For the generation of this map, more than one hundred measurements were made at points of a 250 by 250 mm mesh, and at the points not measured linear interpolations were applied. The probe was kept positioned at 1.5 m above the gazebo ground. This height was chosen since the highest levels, on average, were observed at that level. Figure 3 shows that some points are above the ICNIRP limit. In addition, those points are not only in the vicinity of the parapet.

Through both electric and magnetic field measurement, it was confirmed the existence of a near-field, since the ratio between electric and magnetic magnitude was shown to be

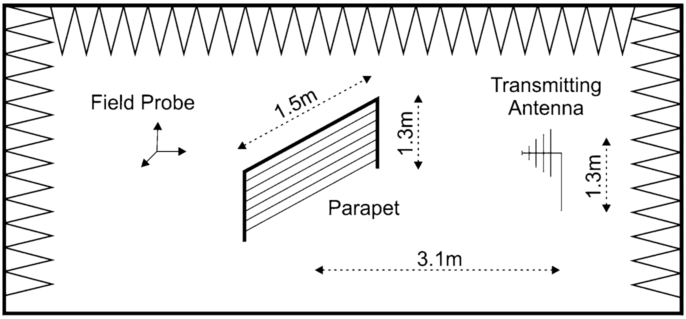

Fig. 4 Experiment setup

Fig. 5 Experiment performed in a semi anechoic chamber

different than 377 Ω. Table 2 summarizes the wave impedance as a function of distance from the parapet.

3.3 Laboratory Tests and Comparison

Prior to the EMF assessment in the anechoic chamber, test setup ambient levels (i.e. all equipment energized) were performed to verify the noise floor introduced by the system. The ambient measurements were performed using vertical and horizontal polarization using a log periodic antenna.

The parapet was separated from the transmitting antenna (Schwarbeck STLP 9128 D) by 3100 mm. The system was calibrated to provide 25 V/m at the parapet with a continuous wave in the horizontal and vertical polarizations. The field probe was then used to measure the field at different locations from the parapet from 90 to 1080 mm. The test plan is depicted in Fig. 4 and the experiment in laboratory in Fig. 5.

Since it was not possible to determine the actual EM waveforms at the observatory, continuous wave measurement was compared with AM and PM modulations. In both cases the message is a 2 kHz signal. There was no significant change related to the type of modulation. For each frequency step the field duration of the measurement is 1 s. The results for vertical (V) and horizontal (H) polarization excitation and the field measured 90 mm from the parapet are shown in Table 3.

Table 3 Laboratory results with a scaled model of the parapet

	89 MHz	103 MHz	104.25 MHz	107.5 MHz
V	8.31 V/m	44.9 V/m	44.8 V/m	41.9 V/m
H	3.5 V/m	14 V/m	6 V/m	4 V/m

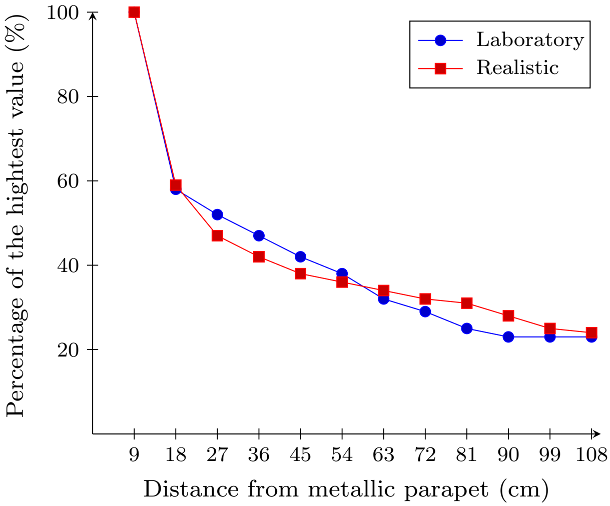

Fig. 6 Comparison between the fields measured in the observatory and in the laboratory

The Fig. 6 shows the comparison between the fields measured in the Observatory (realistic environment) and the sum of four sources measured in the laboratory for all points from 90 to 1080 mm from the parapets. The measures are normalized using as reference the first point (highest value), since the objective is to compare the relative behavior of field due to re-radiation.

3.4 Conclusion

In this paper, the main goal is to discuss nonoccupational human exposure at multi source EMF environment in a public area. It was assessed the EMF exposure in a complex and realistic environment: a brand-new observatory which can be visited by the general public located close to (between 19 and 32 m) to a multi source telecommunication environment. Total exposure was evaluated. Additional measurements were performed in the laboratory within an anechoic chamber to better understand the entire scenario.

For the on-site measurements, it was used a broadband probe, considering the three spatial dimensions (independent of the incident wave's polarization), taking into account also the power density contributions at various frequencies.

Since the equipment is a broadband instrument, a procedure to verify the contribution of each source was performed by stations selective switching off and switching on one by one and observing the contribution of each source. As demonstrated in Fig. 3, the power densities due to each of the sources, coincided with the total power density, measured with all the sources turned on simultaneously. Therefore, it is concluded that the measurements are consistent and have been properly carried out in accordance with current international standards.

The re-radiation phenomenon can generate constructive or destructive interferences in the measured frequency even if originating at different frequencies. The effect of the field variations in the vicinity of the metal parapets has been proven by many repeated measurements. In addition to the simple reflections (more common and easier to explain), it has been shown the existence of re-radiation effects on the metallic parapet, and observed the characteristics of nearby fields. The repeatability of measurements indicates the measured values are reliable, which gave us confidence to make some affirmations regarding the measures taken.

Finally, after this comprehensive case study, in order to protect citizens visiting the Boa Vista Hill observatory, ANATEL the government agency for telecommunication in Brazil demanded the immediate power reduction of the main broadcasting sources as a mitigation action and until a definitive solution was found. At the same time, the municipality designed a Faraday's cage. Another recommended solution was to modify the elevation and/or spacing of the main sources from the observatory. Some broadcasters are planning to do this by changing their projects. To reproduce and isolate the re-radiation phenomena, a parapet with the same characteristics was constructed and the experiment in an anechoic chamber was carried out. The comparisons between the realistic and the laboratory results showed that the electric field had an important increase in the proximity of the parapets, since it acts as a parasitic re-radiation sources.

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