Electromagnetic Characterization of UHF-RFID Fixed Reader in Healthcare Centers Related to the Personal and Labor Health

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ABSTRACT Hospitals and healthcare centers are experiencing a remarkable implementation of new systems based on wireless communications technologies. Many of these systems provide location services and identification of materials, instrumentation and even patients, which promotes the increase of the quality and the efficiency of healthcare. A tracking system based on short-range radio frequency, UHF-RFID is evaluated. This system helps with location of orthopedic prosthesis according to the criteria and requirements of a specific hospital environment. It is characterized the influence of UHF-RFID system in the electromagnetic environment by measuring the parameters and characteristics of the emission levels. The results of the assessment are represented through 2D contour maps and simulations have been performed by means of an in-house 3D-RL algorithm. The proposed graph aims to provide a methodology of studying the electromagnetic environments and the evaluation of the safety conditions of workers, patients, and people in general. E field exposure levels due to the RFID localization system were analyzed in order to verify regulations concerning the safety of patients and the general public in the labor and healthcare fields. Localized electromagnetic field exposure at levels which may cause electromagnetic hazards in the specific healthcare environment have been found and potentially excessive exposure to EMF emitted by UHF RFID devices may apply to patients or bystanders. In all cases, insufficient electromagnetic immunity of electronic devices (including AIMD and other medical devices) should be considered and the electromagnetic hazards may be limited also by relevant preventive measures, as also shown in this paper, together with the principles of an in-situ evaluation of electromagnetic hazards near the UHF-RFID devices.

INDEX TERMS UHF-RFID, E-field strength distribution, electromagnetic hazard, healthcare centers, radiofrequency exposure, 2D contour maps, 3D ray launching (3D-RL), environmental assessment, radiation protection.

I. INTRODUCTION

The implementation of new systems based on wireless communications technologies in healthcare centers has increased

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in the last years. In the context of Smart Cities/Smart Health, heterogeneous wireless network operation is pivotal in order to provide context-awareness, increasing the use of wireless systems in these centers. The use and presence of wireless technologies (employing non-ionizing radiation, mostly from the radiofrequency (RF) range of

electromagnetic field (EMF) have increased exponentially at the same time, extending the technological advances and developments to a large number of applications and services. With more than half of the population living in cities [1] and an average (constantly increasing) of more than 2.4 devices per user connected to the internet in 2018 [2], billions of devices and wireless technologies, interconnected by Heterogeneous Networks (HetNet), are and will be coexisting as Complex Heterogeneous Environments. Information and Communications Systems (ICS) are, unavoidably, sources of electric and magnetic fields, to which a large proportion of the population is exposed. We are immersed in a growing trend of implementation and adoption of new wireless systems in various domains such as domestic, work environments, and of course the healthcare environment with dynamic condition changes and cumulative exposures in terms of spatial and technical features as well as the different user densities, distributions and communication link requirements. EMF exposure characterization, monitoring and evaluation is particularly needed in indoor environments, [3], from domestic household to public environment such as administrative, commercial centers and healthcare environments [4]–[9]. Smart solutions for medical purposes (e-Health) are one of the earliest and already the most widely worldwide implemented smart solutions. Especially the applications of information systems based on Short-range technologies are experiencing a notable boom in the aforementioned environments, especially the following technologies: Radio Frequency Identification (RFID), Bluetooth (BT), ZigBee, ANT, Ultra Wide Band (UWB), Wi-Fi, and Near Field Communication (NFC). Recently also new systems such as fifth-generation (5G) networks, along with technical improvements in miniaturization, the development of novel, smart, small-sized wireless wearable sensors for biomonitoring and sensing applications, popularly known as Short-Range Devices (SRDs), has been enabled for general use [10].

Many of these systems provide location services and identification of materials, instrumentation and even patients. In the healthcare field, these wireless systems are being used to control, record, and transmit a variety of health related data. In relation to the development of medical activity and which constitutes an imminent need in any healthcare environment, is monitoring the location of the material and the location of people or patients. In this scope, they are usually recognized as crucial Healthcare Treatment relying on remote medicine safety, wellness or location control and the tracking of personnel, patients, biological materials and medical devices [11]–[16].

It is projected and installed a tracking system based on UHF-RFID, to locate orthopedic prosthesis according to the criteria and requirements of a specific hospital environment.

Hence, it is compulsory to analyze the effects of exposure of the general and occupational public to electromagnetic fields in healthcare environment, because these scenarios can be affected by UHF-RFID sources of EMF exposure [17], [18]. There are multiple factors to consider with

respect to the biophysical effects of EMF influence and their significance with respect to the safety and health of the population: human body characterization is a complex task, where the behavior of human tissues is based on the frequency under analysis and, hence, there is a vast range of frequencies to study; biological interactions may be thermal from tissue being physically heating by absorbed electromagnetic energy, or more complex non-thermal bioelectromagnetic effects involving various biochemical or bioelectrical processes [19]–[30].

Moreover, exposure to EMF can also cause indirect effects by the presence of an object in an EMF, which may become the cause of a safety or health hazard, such as interference with medical electronic equipment and devices (including implants or medical devices worn on the body), which can even lead to fatal consequences in critical health cases [31]. The pervasive use of wireless communication devices has emphasized the need for assessing RF-EMF exposure, with great interest in ensuring safe exposure conditions considering the health impact and/or potential malfunctions in electronic devices caused by the RF-EMF emissions from the combination of all the available wireless communication systems [32]–[43]. Fig. 1 presents a schematic view of UHF-RFID system that can be involved in healthcare environments [44].
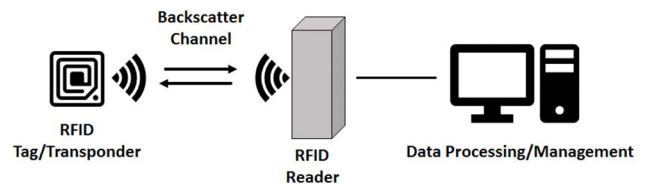

FIGURE 1. RFID basic system components.

Preliminary experimental results were represented through 2D contour maps as conference article [45]. This work is focused on exposure levels due to the UHF-RFID localization system in order to verify regulations concerning the safety of patients and the general public in the labor and healthcare fields. A complete E-field strength distribution study, focusing on UHF-RFID frequency band, is carried out considering the usual E-Field exposure levels in realistic operational scenario to provide an intensive and comprehensive in-depth a tracking system based on short-range radio frequency, UHF-RFID E-field characterization study. An anechoic chamber evaluation of this technology has allowed to assess the exposure conditions in the worst case. The experimental and simulated results are represented through 2D contour maps, and have been compared with the recommended safety and exposure thresholds. Finally, simulations have been performed by means of an in-house 3D-RL algorithm. It must be pointed out that considering the low exposure levels and research results collected to date, there is no convincing scientific evidence that the weak RF signals can cause adverse health effects. Nevertheless, research is still being promoted by WHO [46] to determine whether there are any health consequences from the lower RF exposures levels.

A. UHF-RFID TECHNOLOGY

The bar codes are already fully integrated into the sanitary operation and their utility was unquestionable to avoid the incorrect interpretation of handwritten texts, both when labeling devices, products and biological samples, and when filling in medical records. RFID is the most common and fastest-growing wireless technology of automatic identification and data capture, which identifies and tracks RFID sensors (tags) attached to objects. RFID technology dates back to the 1970s (some sources mention even the 1950s). Over time, RFID technology has evolved, introducing different frequencies, ranges, higher data rates and upgraded characteristics and may be integrated with various wireless communication networks such as WSNs or WLANs.

The most commonly used RFID systems in the world are low frequency (LF band: 30–300 kHz; operating typically at 125 kHz), high frequency (HF band: 3–30 MHz; operating typically at 13.56 MHz frequency), ultra-high frequency (UHF band: 300–1000 MHz; operating in the frequency range 860–965 MHz (in Europe, 865–868 MHz) for passive tags and 443 MHz for active tags), and super-high frequency (SHF bands: 2.400–2.4835 GHz and 5.725–5.875 GHz; operating typically at 2.45 and 5.8 MHz frequency) [47].

Like bar code, RFID allows digital marking, but also contains certain exclusive attributes that introduce promising new use cases for telemedicine and telecare. Thus, while barcodes contain fixed information and can only communicate data when read, requiring visual alignment with the receiver, RFID allows objects to identify themselves without requiring such alignment. On the other hand, the information is not static, but is stored in a rewritable memory contained in a tag which can be attached or incorporated into products, animals and people.

These tags embed antennas, which allow them to receive and respond to requests for information via radio frequency. The data exchanged will, in turn, be processed in a remote computer system for a specific use, for example, for the management of stocks in any warehouse, for the monitoring of the drugs themselves from the laboratory to the point of sale to avoid theft or adulterations, or, within the sanitary precincts for the trace of the clinical or surgical material (marking goods, wares, devices, and books, document tracking in offices, or even patients, biological material or pharmaceuticals). This software can be configured in order to provide access of real-time data relevant to each tracked material for different groups or specific personnel and provide information of historical reporting functionality and to demonstrate compliance with various regulations and provides a powerful data collection tool for facilities seeking to improve operational efficiency and reduce costs of various processes. Applications based on the integration of radiofrequency identification with other ubiquitous computing technologies, such as communications protocols and wireless sensor networks, Internet of Things (IoT) and specially Internet of Medical Things (IoMT) are also being introduced to support our daily lives and address our health in so-called assisted environments with a minimum of human intervention.

One of the frequency bands in which they can operate is that of UHF, in Spain 865-868 MHz, on which this work focuses. An UHF-RFID reader reads and writes data on tags and power up the passive tags that receive electromagnetic energy by wireless interaction from a nearby UHF-RFID reader interrogating tags. They may use fixed readers and handheld readers equipped with antennas of various dimensions. Handheld readers usually operate with antennas of dimensions smaller than 20 centimeters, which are built into small portable electronic intelligent devices or are a kind of periphery accessory [48].

The advantages of this technology in healthcare centers has promoted it's use in a wide variety of rapidly developing applications, such as monitoring, controlling or managing objects in medical centers and the public environment. Taking into account the popularity and widespread use of this technology, it is compulsory to analyze in-depth non-ionizing radiation exposure in this type of environment and verify compliance with legal exposure limits.

One of the most prominent applications of RFID within health centers is the monitoring of clinical material and other hospital goods. The utility for the monitoring and location of patients, especially those most vulnerable by age (elderly and children) or by the type of ailment (dementia, Alzheimer's ...) as well as in relation to the treatment of blood, is becoming more important, either for diagnostic or therapeutic purposes. As with barcodes, the environment of hemotherapy and transfusion medicine pioneered the incorporation of RFID innovations that positively result in patient safety.

For the author's knowledge, there are a limited amount of studies of EMF exposure about the human exposure to RFID systems in these clinical applications, operating at a frequency of the present work of 865-868 MHz. The evaluation of the EMF exposure of an RFID reader with respect to the limits established for the implant-bearing population may be insufficient to protect the implant user. In these environments, electromagnetic fields exposure presents particular features, given by the fact that individual exposure levels can be affected by the emission from personal communication devices of nearby users.

Previously, the authors presented in [49] the study of EMF emitted by RFID handheld readers (UHF-RFID guns) and tags and were characterized and evaluated with respect to humans exposure metrics – the strength of the electric field affecting anyone present near UHF (ultra-high frequency) RFID guns and the specific absorption rate (SAR) values in their body.

1) SCENARIOS OF EXPOSURE TO EMF NEXT UHF-RFID DEVICES

Reports in the literature on RFID technology mainly concern the design of low cost, simplified antennas with circular polarization, allowing tag detection from the greatest

possible range [49]. In this context, estimations of SAR (6-minutes averaged) for various anatomical human body models exposed to EMF emitted by a UHF RFID reader with an antenna of circular polarization, in various locations and distances (10, 20, 50 cm) against human body models have been obtained. Within the vicinity of readers with higher power ratings, SAR values may be exceeded in an exposure time shorter than the 6 minutes interval considered above.

Other applications of RFID are those based on the integration of radio frequency identification with other ubiquitous computing technologies, such as communications protocols and wireless sensor networks, to support assisted environments in the health context. However, it is not possible to ignore that the immediate consequence of creating environments supported by wireless systems will be the notable increase in electromagnetic emissions and EMF around people, which makes it essential to analyze their risks and determine, if necessary, the most appropriate security measures. The advantages of wireless technology in healthcare centers is leading to a wide variety of rapidly developing applications, such as monitoring, controlling or managing objects. The expected benefits of RF identification technologies for health could be questioned if the acceptable thresholds for EMF exposure of multiple field components and in many cases, continuous, are not determined exactly. It is also essential that the technical conditions that would avoid interference with other devices or systems, mainly electromedical, be established unequivocally. How these critical factors are addressed may depend on their acceptance or rejection by health service providers, sector professionals and patients.

The UHF-RFID platform under analysis is located within different floor levels and locations of the Hospital Universitario de Canarias (HUC), where the different devices that integrate the platform will be deployed, which influences the areas that will be affected by radio emissions frequency from UHF-RFID devices. The operation protocol was determined and once the platform was installed, the requirements compliance were checked. The UHF-RFID device evaluated are presented in Fig. 2:

In general, UHF RFID systems have the limit of effective radiated power (ERP) from the antenna fixed maximum 2 W for devices where use does not require special permission in accordance with ETSI/EN 302-208 V3.1.1:2016-12, being a harmonized standard with Directive 2014/53/EU (recognized as the RED directive). This is the case for the deployment under analysis in this work.

2) GENERATION OF 2D CONTOUR MAPS

This paper analyzes the signals emitted by our RFID system in a ward of the HUC, and presents a methodology to generate a graphic and accurate 2D contour map of the EM fields. After collecting all data, they were transferred to the specific software (SURFER 8) to create 2D contour maps according to the previously measured levels of intensity. Surfer is a contouring and surface mapping program that runs under Microsoft Windows. It converts data into outstanding
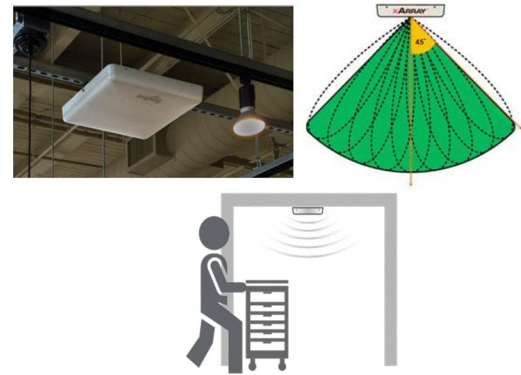

FIGURE 2. Devices of location and identification of material, instrumentation and even of patients frequently used UHF-RFID: fixed reader RFID xArray Gateway R680 (ETSI).

contour, surface, wireframe, vector, image, shaded relief, and post maps.

3) EMF EXPOSURE METRICS AND EVALUATION

In most countries, EMF regulations and legislation and thus, RF-EMF radiation exposure limits, are based generally on the two most international adopted guidelines and standards, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines (ICNIRP 2020) [19] or the Institute of Electrical and Electronics Engineers (IEEE) standard C95.1-2019 by the IEEE International Committee on Electromagnetic Safety [50]. In general, EMF exposure limits are adequately established in order to attend two main different group of population: occupational and general public, with independency of the selected EMF standard or guideline.

On March 2020, the International Commission on Non Ionizing Radiation Protection (ICNIRP) announced that it had released new guidelines on radiofrequency radiation (RF) exposure levels. These will replace the current guidelines that have been in place since 1998. The ICNIRP Guidelines are promoted by the World Health Organization and form the basis for radiation standards in many countries. The updated Guidelines cover the frequencies that will be used for new 5G technologies, as well as those currently used for wireless and radio transmissions in the range 100 kHz to 300 GHz.

Limits for general public and worker exposure are different in the 2020 ICNIRP recommendation based on the guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [19] that updates the radiofrequency electromagnetic field (RF EMF) part of the ICNIRP 1998 guidelines and recognized by the World Health Organization (WHO) [46]. The body of scientific information has not increased greatly higher than the ICNIRP (1998) restrictions, particularly in terms of thermal effects. However, there are two new restrictions in ICNIRP (2020) that have the potential to further strengthen health protection. The first relates to the development of technologies that utilize EMF frequencies >6 GHz, such as 5G, with new restrictions to

better protect against excessive temperature rise in the body. The second relates to brief RF EMF exposures (<6 minutes), to ensure that transient temperature rise is not sufficient to cause pain or adversely affect tissue, although the present guidelines do not provide protection for low intensity exposure of long durations and over the whole body.

The averaging time for this restriction has also been changed from 6 minutes in ICNIRP (1998) to 30 minutes in ICNIRP (2020), to better match the time taken for body core temperature to rise. Particularly relevant for ensuring safety with future technologies, such as 5G, which beams are not 'sufficiently' focused to cause harm. ICNIRP (2020) provides additional restrictions to ensure that exposures over brief intervals do not result in excessive temperature rises. These restrictions are set as a function of exposure duration, and are applicable to both continuous (e.g. sinusoidal) and discontinuous (e.g. pulsed) RF EMF. ICNIRP (1998) provided reference levels for continuous whole-body exposures. However, those reference levels did not cover all of the types of basic restriction. ICNIRP (2020) provides reference levels corresponding to all the basic restrictions.

Research has now better determined the relations between basic restrictions and both the electric and magnetic field reference levels, and ICNIRP (2020) has updated these reference levels to incorporate our improved knowledge and the reference levels have been increased accordingly.

The experimental data have been compared with the recommended safety and exposure thresholds to provide reliability of the prediction procedures of the exposure levels in the indicated environments. Evaluation of exposure levels due to the UHF-RFID localization system is provided in order to verify regulations concerning the safety of workers, patients and the general public in the healthcare environment and should be considered to assure a proper, reliable and safe usage of the RFID localization system.

Research has shown that to match the whole-body basic restrictions, this increase should start at 30 MHz. ICNIRP (2020) thus has a monotonous increase in both the E- and H-field reference level values with decreasing frequency, that begins at 30 MHz. These differences can be seen in Fig. 3 and Fig. 4. New scientific knowledge allowed rules to be set in ICNIRP (2020) for the application of reference levels in the near- and far-field separately. This will ensure that exposures within the near-field zone will not result in over-exposure. In addition, although ICNIRP (1998) allowed E-field and H-field to be used for whole-body average reference levels across the entire 100 kHz to 300 GHz frequency range, this method can potentially result in inaccuracies for frequencies above about 2 GHz within the near-field zone and so is not permitted within the new guidelines; measures of power density must be used instead.

The evaluation has been carried out in accordance with the regulations applicable in Spanish territory. With regard to the protection of the general public, Royal Decree 1066/2001, of September 28 [51], which approves the Regulation that establishes conditions for the protection of the radioelectric
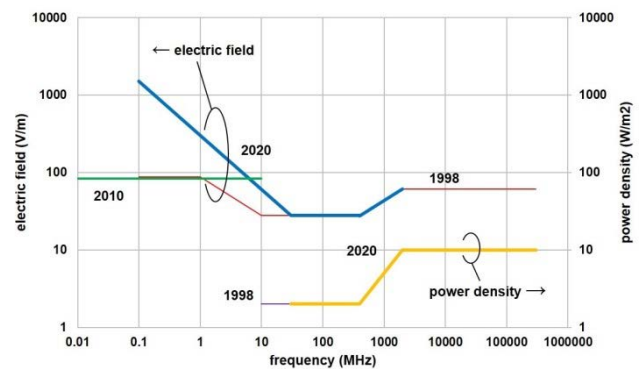

FIGURE 3. Whole body average reference levels for the general public for the ICNIRP (1998), ICNIRP (2010) and ICNIRP (2020) guidelines, for the 100 kHz to 300 GHz frequency range [5]. Note that the units of the two y-axes (i.e. electric field and power density) are independent of each other.
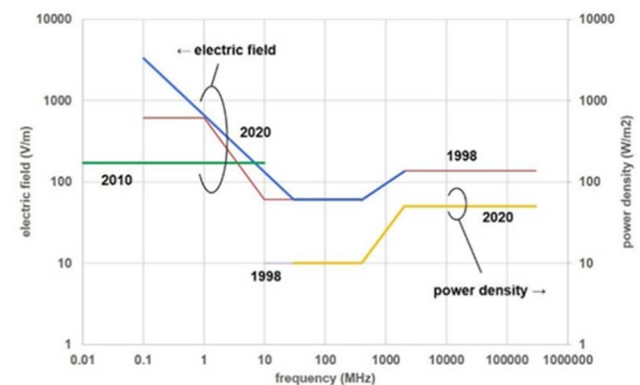

FIGURE 4. Whole body average reference levels for workers for the ICNIRP (1998), ICNIRP (2010) and ICNIRP (2020) guidelines, for the 100 kHz to 300 GHz frequency range. Note that the units of the two y-axes (i.e. electric field and power density) are independent of each other [5].

public domain, restrictions on radioelectric emissions and sanitary protection measures against radioelectric emissions, the transposition of the European recommendation 1999/519/EC allowed a harmonized vision of the protection of health against non-ionizing radiation in all the European Union [52].

Regarding the protection of workers, the transposition of the European Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 [31] is reflected in the Spanish Royal Decree 299/2016, of July 22 [53] on the protection of the health and safety of workers against the risks related to exposure to electromagnetic fields. "Occupational exposure" is applied to those individuals who are exposed to EMFs as a result of performing their regular job activities. This legal text establishes exposure limits for the protection of workers' health from the immediate effects of short time exposures to non-ionizing radiation, which in the case at hand, of RF signals, would be potentially harmful thermal effects.

In real conditions, the exposure to the emissions of the equipment studied will be considered occupational, with the workers being exposed in a non-continuous and non-homogeneous way. In Fig. 3 and Fig. 4 are showed the exposure limits for electric and magnetic fields, for occupational and general public exposure, published by ICNIRP 2020, the most extended standard in Europe.

There are a range of improvements to the ICNIRP (2020) restrictions, including the addition of new restrictions, amendments to old restrictions, and the removal of some restrictions. Additional restrictions were introduced to account for situations whereby the ICNIRP (1998) restrictions would not adequately account for new technological developments, such as aspects of 5G technologies; amendments to existing restrictions were made to improve precision based on scientific advances since 1998, such as more accurate knowledge concerning the relation between spatial averaging of exposure and temperature rise. There are a range of improvements to the ICNIRP (2020) restrictions, including the addition of new restrictions, amendments to old restrictions, and the removal of some restrictions.

A new restrictions in ICNIRP (2020) that have the potential to further strengthen health protection. One of them relates to the development of technologies that utilize EMF frequencies >6 GHz, such as 5G, with new restrictions to better protect against excessive temperature rise in the body. This allows a simpler means of assessing compliance with all the basic restrictions as is showed in Fig. 3 and Fig. 4. 'Guidance' has been provided to help inform those responsible for occupational RF EMF exposures, to assist them in ensuring that this hazard is understood, and accounted for in an appropriate health and safety program.

This work is organized as follows: in Section II (MATERIALS AND METHODS), the measurements campaign, graphic presentation and simulation scenario are presented. In Section III (RESULTS), the results obtained are explained, the indoor geographical representation of the UHF-RFID device where different transmission positions have been showed as well as simulation parameters. Section IV (DISCUSSION) presents discussion in relation with the simulation and measurements results and different exposure level thresholds, showing that E-Field results are below the maximum reference levels of ICNIRP. In Section V (CONCLUSIONS) are presented. In consequence, a simulation-based analysis methodology is provided, aiding in the assessment of future wireless deployments.

II. MATERIALS AND METHODS
A. MEASUREMENTS CAMPAIGN
A campaign of measurements was designed and implemented in two different locations in Spain, (Tenerife, Canary Islands and Madrid) to analyze the UHF-RFID technology. The corresponding received E-field distribution levels has been obtained, thus, compliance with legal exposure thresholds can be assessed. An UHF-RFID location system has been designed and installed for the location of prostheses attending to HUC criteria. The implementation of the UHF-RFID platform involves the choice of the location where the different devices that make up the platform were located, which influences the areas that will be affected by radio frequency emissions from RFID devices. Once the platform is installed, the fulfillment of requirements are analyzed. The evaluation of electromagnetic emission levels were carried out in order to guarantee the safety of patients, workers and the general population. The characterization measures of the EIRP in the worst case were carried out in the Radio Frequency Laboratory, Dirección General de Telecomunicaciones y Ordenación de los Servicios de Comunicación Audiovisual (Madrid).

On the other hand, the generated electric field values, both in far-field and near-field conditions, must be taken into account to analyze the possible operating problems that may affect the operation of other wireless networks operating in the vicinity, including in addition the appliances that can emit in the same frequency of operation. For each of the distances from the antenna to the equipment, the measurements were made by accumulating a maximum of three measurement cycles to obtain the maximum emission measurement of the equipment. Once the EIRP was characterized the adequacy of the established European regulations was verified.

There are different strategies and methodologies to monitor the EMF exposure. In this work, two types of evaluations have been carried out: in the HUC the measurements have done in the places where the UHF-RFID technology has been installed for evaluation: an array on the roof of a wide room. In Madrid, evaluation was carried out in anechoic chamber in worse case situation. Both methods are experimental protocol for measuring the spectral distribution of radio frequency (RF) energy by means of frequency selective measurement equipment (band 865 - 868 MHz) to determine the signal strength of a specific frequency in positions and configurations of maximum emission. The system under test is a Fixed RFID reader xArray Gateway R680 (ETSI), connected to Impinj's ItemSense software, to enable asset or item identification, location information and zone transition information, among others.

1) HOSPITAL MEASUREMENTS
The spectral distribution of radio frequency (RF) energy has been studied via selective frequency measurement tools in the HUC at 865-868 MHz frequency range. The influence of RFID on the environment is defined by the measurement of the variables and features of the emission levels [45].

The monitoring has been performed by means of a Rhode & Schwartz FSH6 spectrum analyzer and a receiving antenna ETS-LINDGREN, Mod.3182 (500MHz-9GHz), shown in Fig. 5. The spectrum analyzer performs measurements of E, and the representation, identification and monitoring of the signals within the environment under study. The broadband omni-directional antenna is designed for surveillance, spectrum monitoring, and shielding studies. The polarization offering the highest field intensity was chosen. In the

FIGURE 5. Equipment for spectrum evaluation: Rhode & Schwartz FSH6 spectrum analyzer and receiving antenna on tripod ETS-LINDGREN, Mod. 3182.

TABLE 1. Fixed RFID reader xArray gateway R680 (ETSI).

Description	Characteristics
Air Interface Protocol	EPCglobal UHF RFID Class 1 Gen 2 / ISO 18000-63
Max Receive Sensitivity	-82 dBm
Location Accuracy	85% within 1.5 m in ideal conditions; 66% within 1 m in ideal conditions
RF Beams	52 Dual-Polarized Beams
Effective Field of View	±45° from 0° (underneath the xArray)
Dimensions	46.7 cm in H x 46.7 cm in W x 7.5 cm in D)

rooms where it was installed, prior to installation, there was no radiant technology at the operating frequencies that we have evaluated. Impinj's ItemSense software enables real-time Item Intelligence, centralizes, and automates the management and monitoring infrastructure that offers item or asset identification, location information, and zone transition.

The xArray provides always-on, wide-area monitoring for real-time identification, location, and direction of RFID tagged items. The technical characteristics are presented in Table 1. The xArray was positioned on center of the ceiling of a room without windows and with a door, around 3.5 m high, covering an estimated zone of 4 × 4 meters. Measurements are carried out at 100 cm and 170 cm heights from floor level.

The solution offers automated control of stock in real time in areas at room temperature. This is done automatically thanks to the previous tagging with RFID TAGs of the stored product, being able to manage the products individually or through double compartment management in ISO baskets or shelves. The monitoring, reporting and control of the system is carried out by the management software, which is responsible for device management and at the same time provides access to parameter reports. With this procedure, we were
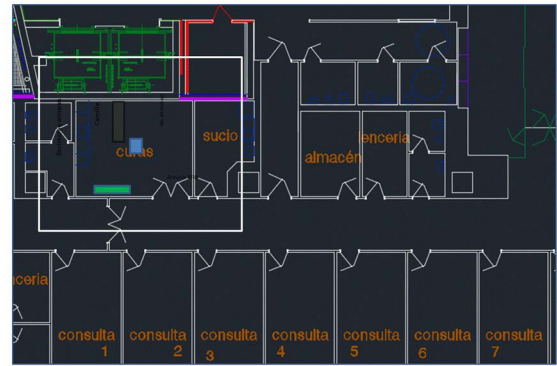

FIGURE 6. Floor plan of the scenario generated with AutoCAD in which the fixed RFID reader xArray Gateway R680 is introduced.
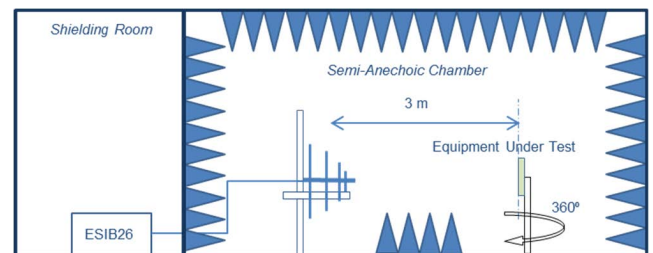

FIGURE 7. Measurement setup for the radiation patterns measurements inside the anechoic chamber.

able to analyze different areas, measuring E-field levels in the closest area where devices are in use.

2) EVALUATION IN SEMI ANECHOIC CHAMBER
The radiated emission characteristics of the devices under test have been obtained by performing measurements within the RF Laboratory of the Dirección General de Telecomunicaciones y Ordenación de los Servicios de Comunicación Audiovisual (Ministerio de Asuntos Económicos y Transformación Digital), which includes among others equipment and software relevant to the topic considered such as showed in Table 2. Laboratory measurements have been carried out to characterize and analyze the emissions of a XArray that operates at 865-868 MHz, in order to obtain the radiation pattern of the XArray and identify maximum field orientation.

The measurements to obtain the radiation pattern in worst case were performed in a semi anechoic chamber, shown in Fig. 7 and Fig. 8. The room has dimensions of 9.76 m × 6.71 m × 6.10 m, the walls are lined with a foam based radiofrequency absorber material (RANTEC Ferrosorb300) specified to have a re-flection/absorption coefficient of −18 dB at the frequency of RFID center frequency 865.73 ± 0.05 MHz, at a distance of 3 meters and the distance to the floor was 1.5 m.. The measurement antenna was placed in the two polarizations and moved in height to find the maximum signal level, at the 0° angle (measurement antenna facing the emitting equipment). Once the maximum level of field intensity had been recorded, the intensity values were
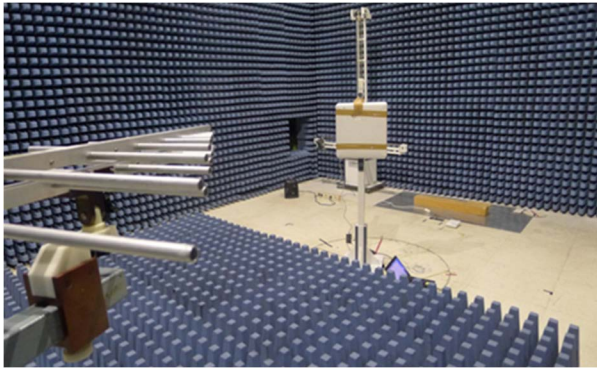
FIGURE 8. Measuring antenna and positioners required for the radiation patterns measurements inside the anechoic chamber.

TABLE 2. Laboratory equipments.

Equipment	Marque - Brand	Model
EMI Receptor	Rohde &Schwartz	ESIB26
RF Generator	Rohde &Schwartz	SMT02
Log-Period Antenna	EMCO	3146
Semi anechoic chamber	IRSA	3m
Software	Rohde &Schwartz	EMC32-E
Mast	EMCO	1050
Table	EMCO	1060-1.2

characterized by rotating the antenna in steps of 45 degrees. Subsequently, the same was done, at distances of 1 and 0.5 meters, in these cases, the level of Effective Radiated Power (ERP).was measured and with these data the level of field intensity was calculated. Moreover, this location was employed in order to measure the EMF exposure levels in the most probable location for patients, workers or general public. In addition, no other wireless devices, were used during the data collection process, avoiding inaccurate or incorrect measurements. A positioner with an EMCO 1051 motor allows the changes of the measuring antenna between the horizontal and vertical position. The measurements were carried out with an EMI Test Receiver ESIB26, Rhode & Schwartz with a frequency range of 20 Hz - 26.5 GHz, and the measuring antenna is an EMCO 3146 log-period antenna with a frequency range of 200 MHz - 1 GHz and those showed in Table 2.

After obtaining the radiation pattern, the position of each tested device at which the electric field strength is maximum was fixed. In that position the electric field strength was measured as a function of the distance in near field conditions to check the influence on other wearable electrical devices

3) 2D GRAPHIC REPRESENTATION

A methodology for the generation of 2D contour maps that provide a graphic, immediate and accurate representation
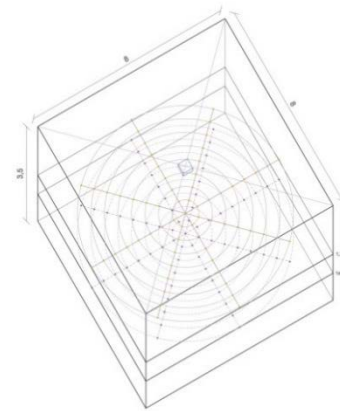

FIGURE 9. Grid and measure points in a care room of the HUC for XArray spectrum evaluation.

of the EM fields of RFID xArray has been developed. The experimental data are represented by means of 2D contour maps, and have been compared with the recommended thresholds for both safety and exposure to provide reliability of the prediction methods of the exposure levels in our environments. Evaluation of our exposure levels results is provided so as to verify regulations regarding the safety of workforce, patients and the general public in the healthcare environment and should be contemplated to guarantee an appropriate, reliable and safe usage of the RFID localization system. Data collected were transferred to the graphic software SURFER 8 which draws lines and colors areas according to the previously measured levels of E field intensity. Radiation graph with the measurement points were located and the measurement points selected are represented in Fig. 9. An alphanumeric codification system was established, in order to identify the location of any measurement point in the database designed for the storage and management of the measurements.

4) RAY LAUNCHING SIMULATION

With the aim of analyzing electromagnetic environment due to UHF-RFID devices within hospital, it is highly important to have the knowledge of the effects that exposure to electromagnetic fields has in the human body. A priori, the most precise way to estimate electromagnetic exposure and perform dosimetric evaluation is obtained by in situ measurements. However, to obtain insight on the potential impact of different wireless devices and their integration as complete systems requires the use of theoretical estimations. On the other hand, these theoretical estimations exhibit some problems, related to the accuracy of the radio propagation parameters and to the human body characteristics. There is a great assortment of techniques to estimate radio propagation and representing the human body. The most accurate method to perform dosimetric estimation is directly solving Maxwell's equations, in which SAR calculations are achieved using full wave techniques such as Finite Difference Time

Domain [54]–[56], or equivalent methods, which enable near field calculations. This leads to a commitment between the computational complexity in terms of calculation time and the final accuracy of the results. However, the large requirements in terms of memory use and the high computational cost make them inappropriate for large area calculations at high frequency bands. The search for optimized evaluation of SAR values has led to enhanced estimation procedures, including modification of the measurement setup to maintain level of exposure and field uniformity, such as described in [57]–[59].

In order to obtain E field estimations within the complete volume of the indoor scenario under analysis, an in-house implemented simulation algorithm has been employed, based on deterministic 3D Ray Launching technique in Matlab environment. In this way, estimations based on reference level, in far field conditions can be provided within the scenario, considering all of the topological parameters, as well as the frequency dispersive material parameters (i.e., dielectric permittivity and conductivity) for each one of the elements included. The simulation code is based in the application of Geometric Optics combined with Uniform Theory of Diffraction, in which rays are launched following a solid angle distribution, for each one of the transmitting sources considered within the scenario and computing transmitted, refracted and reflected rays by application of frequency and polarization depended Fresnel coefficients. Diffraction is also taken into account by performing edge detection and computing losses based on diffraction coefficient estimation. In order to decrease computational cost and hence enable characterization of large, complex scenario, a hybrid simulation approach has been implemented, based in the use of neural network ray interpolators (to decrease launching resolution), the combined use of 3D RL with electromagnetic diffusion equation, based on transport theory in order to decrease computational cost related with the consideration of diffraction in 2D planes and the use of deep learning techniques, based on collaborative filtering, in order to reduce computational cost, by taking advantage of pre-computed canonical scenarios.

The application of the 3D RL simulation code is based in the implementation of the scenario under test (i.e. hospital ward previously described) at Departamento de Ingeniería Eléctrica, Electrónica y de Comunicación, Universidad Pública de Navarra (UPNA). To this extent, the sizes, shapes and specific materials have been considered, with the parameters, obtained from consolidated characterization found in the literature, given in Table 3. Once the scenario has been implemented, the scenario is meshed employing variable sized cuboids. The simulation parameters (angular ray resolution, cuboid mesh size and maximum number of rays until extinction) are given in Table 4 and have been chosen based on previous convergence studies as well as meshing effect studies performed on the specific 3D RL code implemented. The same scenarios of Fig. 6 have been implemented in the 3D-RL tool, considering in both cases all furnishings and the dielectric properties of the materials employed, considering not only the free space loses, but also

TABLE 3. Material properties for 3D ray launching simulations.

Material	Conductivity (σ) [S/m]	Relative Permittivity (ε_r)
Aluminum	$37.8 \cdot 10^6$	4.5
Steel	$7.69 \cdot 10^6$	4.5
Nylon	0.24	1.2
Wood	0.21	2.88
PVC	0.12	4
Polypropylene	0.11	3
Glass	0.11	6.06
Concrete	0.02	25
Rubber	$1 \cdot 10^{-14}$	2.61

TABLE 4. Parameter configuration for 3D ray launching simulations.

Parameter	Value
Operation Frequency	865-868 MHz
Transmitted Power	3.16 mW-2W
Horizontal angular resolution ($\Delta\Phi$)	1º
Vertical angular resolution ($\Delta\theta$)	1º
Permitted maximum reflections	6
Cuboids size (Mesh resolution)	50cm x 50cm x 50cm
Diffraction phenomenon	Activated

other phenomena like reflection, diffraction or refraction. Different simulations have been performed emulating UHF-RFID device emitting at the same positions as they worked in the measurement campaigns. These simulations give results for E-field levels for the whole 3D scenario, which enable the comparison of the received E-field levels at the same spatial point as the measurements. The frequency band simulated has been 865-868 MHz. The considered transmitted power for simulation follows the maximum and minimum transmitted power permitted for the frequency band, shown in Table 4. EU 2014/53/EU (RED) Commission Implementing Decision of the operation of the Radio Equipment Directive on harmonization of the radio spectrum for use by short-range devices.

In order to gain insight in relation with the E-field distribution with the hospital ward, two different simulation scenarios have been implemented. The first one emulates the hospital ward, considering the real dimensions of the scenario, as well as the topo-morphological characteristics. A second scenario has also been implemented, corresponding to the previously described test scenario (i.e., 8.2m*8.2m room) in which measurements have been performed. The characteristics of the RFID transmitter antenna have been considered within the 3D RL algorithm, defining volumetric radiation diagram and the corresponding transmitter output power. The results have been obtained for the complete volume of the scenario under analysis, with particular cut planes presented for the sake of
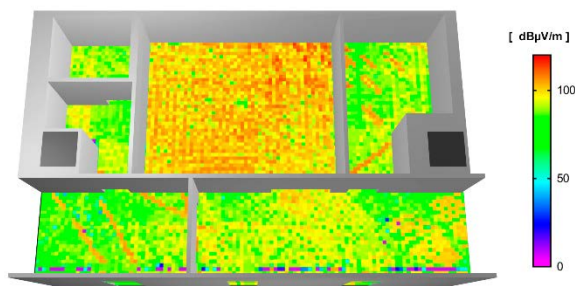
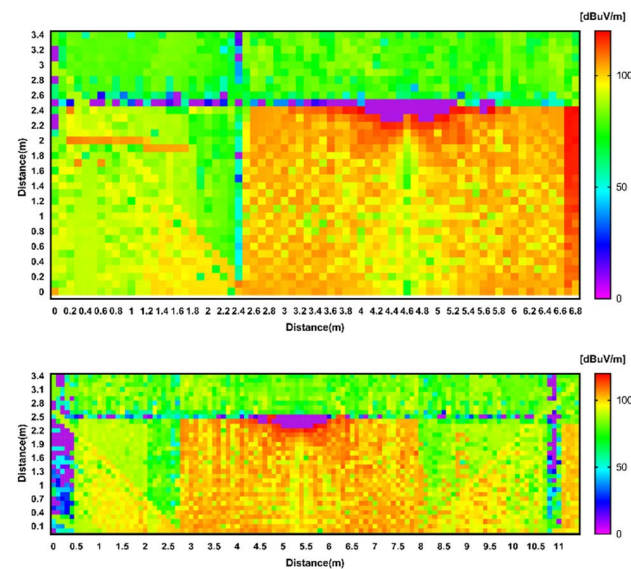**FIGURE 10.** E-field distribution within the hospital ward simulation scenario.

FIGURE 11. E-field distribution within the hospital ward simulation scenario particularized for a) cut plane XZ Y=4.6m, b) cut plane YZ X=5.4m.

FIGURE 12. E-field estimation detail within the 8m*8m test scenario a) cut plane height 1m, b) cut plane height 1.7m.

FIGURE 13. E-field estimation detail within the 8m*8m test scenario a) cut plane XZ, Y=4-1m, b) cut plane YZ, X=4.1m.

clarity. For the case of the ward scenario, E-field distribution within cut plane heights at h=1m and h=1.7m are presented in Fig. 10. As expected, higher values are observed inside the room in which the RFID array is located, being detectable along the complete surface of the scenario. As height is increased, the average detected E-field values also increase, as the observation points are closer the to the transmit array, an effect that can be observed in more detail in the E-field distributions within XZ planes locations, depicted in Fig. 11.

The simulation scenario for the specific room in which the RFID equipment is located has also been implemented and volumetric E-field estimations have also been obtained for this case. The corresponding results for specific XY as well XZ planes are shown in Fig. 12 and Fig. 13, respectively, following a similar trend in relation with E-field amplitude as a function of height and relative observation location.

In order to validate the E-field estimations obtained with the 3D RL deterministic approach, measurement results have been obtained for the ward scenario, considering different angular radials (with orientations of 0°, 45°, 90° and 135°)
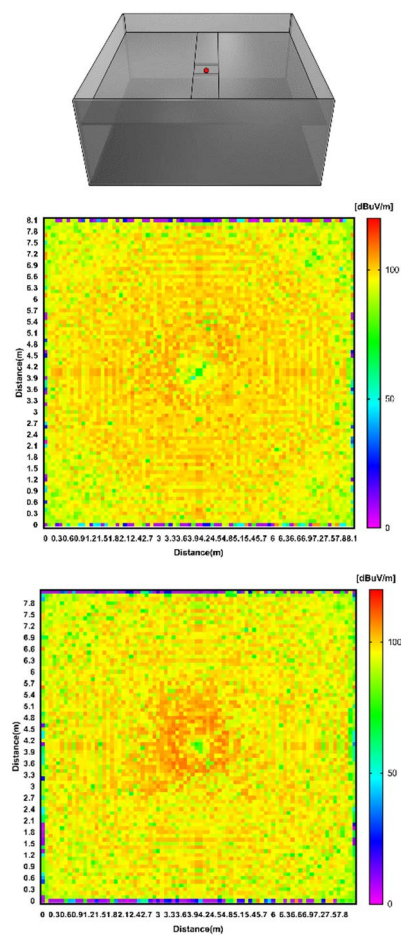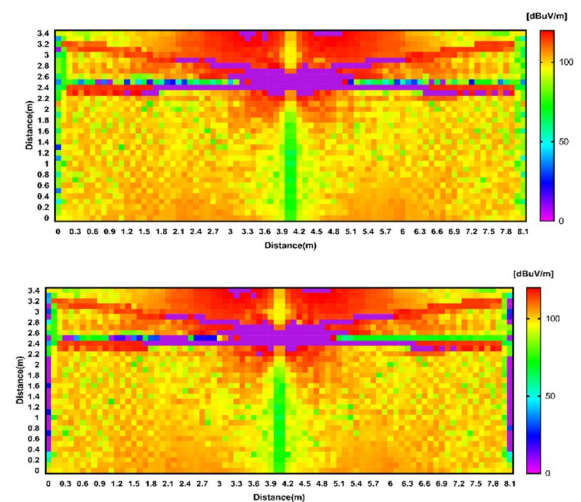
and different cut-plane heights (h=1m and h=1.7m) within the room. The results are given in Figs. 14 to 17, for each of the radial angles previously indicated, showing good agreement between the simulation and measurement values,
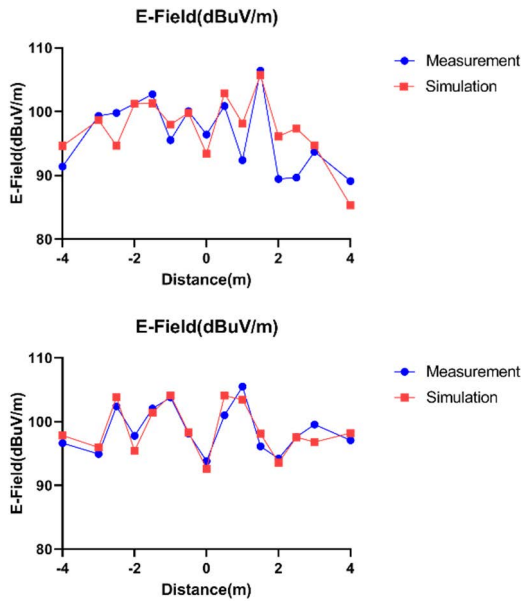
FIGURE 14. E-field estimation within a linear radial distribution, 0° orientation a) cut plane height 1m, b) cut plane height 1.7m.
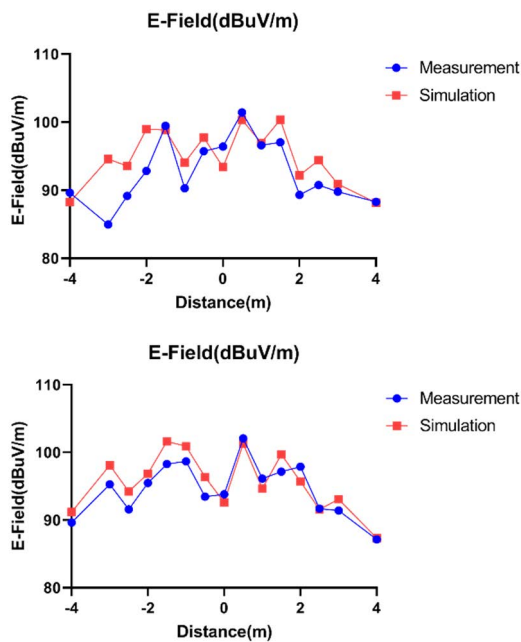

FIGURE 15. E-field estimation within a linear radial distribution, 45° orientation a) cut plane height 1m, b) cut plane height 1.7m.

FIGURE 16. E-field estimation within a linear radial distribution, 90° orientation a) cut plane height 1m, b) cut plane height 1.7m.
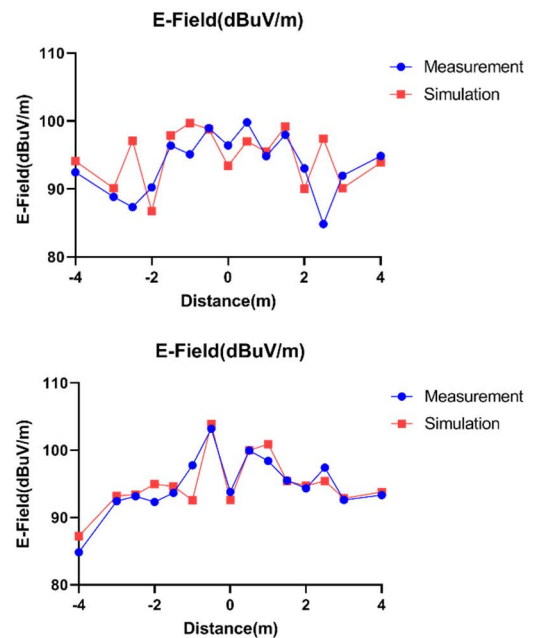
FIGURE 17. E-field estimation within a linear radial distribution, 135° orientation a) cut plane height 1m, b) cut plane height 1.7m.

indicating the adequate estimation capability of the proposed 3D RL deterministic approach to perform volumetric E-field estimation mapping.

III. RESULTS
A. MEASUREMENTS RESULTS
1) HOSPITAL MEASUREMENTS
Several graphs have been obtained with the measurements corresponding to two height planes from the floor in case of XArray antenna system. Level curves of the EMF observed
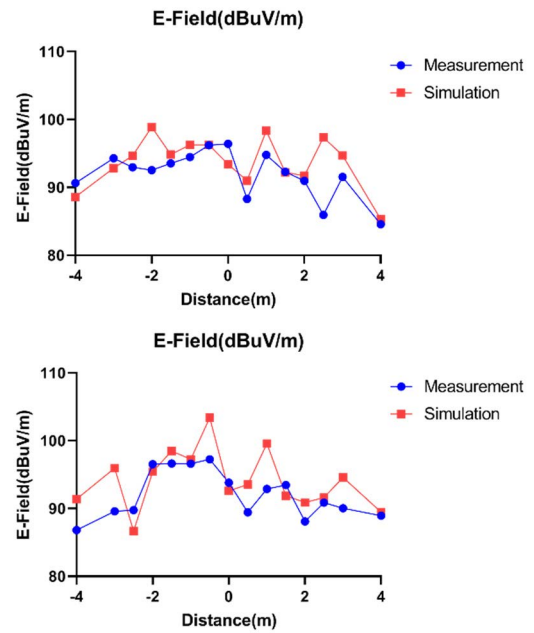
have been represented on them. The recording distances were measured from the vertical on the floor of the center of the transmitter (d = 0) to a distance d = 4 meters, taking intensity values every 50 cm. For the measurement angles, the xArray itself was taken as a reference, and records were made between 0 and 315°, with a 45° spacing. The electric field measures were taken at 100 and 170 cm heights above

TABLE 5. xArray maximum electric field values in dBµV / m at 100 cm.

Distance /angle (dBµV/m)	0	45	90	135	180	225	270	315
0	96							
50	101	101	88	100	100	96	96	99
100	92	97	94	95	96	90	94	95
150	106	97	92	98	103	99	94	96
200	89	89	91	93	101	93	93	90
250	90	91	86	85	100	89	93	87
300	94	90	92	92	99	85	94	89
400	89	88	85	95	91	90	91	92

TABLE 6. XArray maximum electric field values in dBµV / m at 170 cm.

Distance /angle (dBµV/m)	0	45	90	135	180	225	270	315
0	94							
50	101	102	89	99	98	93	97	103
100	106	96	93	98	104	99	97	98
150	96	97	93	96	102	98	97	94
200	94	98	88	94	98	95	97	92
250	98	92	91	97	102	92	90	93
300	99	91	90	92	95	95	90	92
400	97	87	89	93	97	90	87	85

TABLE 7. Summary xArray maximum electric field emitted (V/m).

RFID, Emitter	Equipment RFID: xArray RFID R680
Frequency	865.7 MHz
E max. (V/m) Madrid	Semi anechoic chamber. Height: 100 cm Distance: 50 cm Angle: 0 º V/m: 15.88
E max.(V/m) Tenerife	Ward (xArray on ceiling) Height: 100 cm Distance: 150 cm Angle: 0 º V/m: 0.21
RF – ocupational: NA: E (V/m)	NA = 88.3 V/m Radiated measurements: 17.98%. 0.24% NA
RF- general public NR: E (V/m)	NR = 40.5 V/m E max. emitted: 39.2%, 0.5% NR

FIGURE 18. Radiation pattern of the measured E-Field.

the floor, resembling the position of the head of the seated or standing workers respectively. Values obtained are presented in Table 5, Table 6, Table 7 and Table 8.

At both heights, 100 and 170 cm, recorded E field intensity values were generally in the range 92.04 and 99.08 dBµV/m. However, at the angle 0°, at the height of 100 cm and at a distance of 150 cm in the vertical of the emitter a peak of intensity of 106.44 dBµV/m was recorded. Somewhat lower values of 102.92 dBµV/m and 101.58 dBµV/m were recorded at the 180° angle, at distances of 150 and 200 cm, respectively.
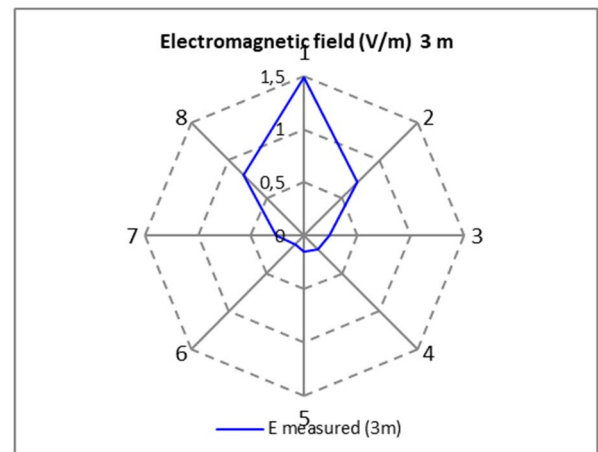
Also at the height of 170 cm, at the 0° angle and at a distance of 100 cm, a peak of 105.58 dBµV/m intensity was recorded, obtaining somewhat lower values, 104.08 dBµV/m and 102.28 dBµV/m, at the 180° angle, at distances of 100 and 150 cm respectively.

2) EVALUATION IN SEMI ANECHOIC CHAMBER

The maximum values, 15.88 V / m and 10.68 V / m, were recorded, as expected, at the shortest distance, 50 cm from the transmitting antenna and at the 0° and 45° angles, respectively. The values were drastically reduced (to approximately 3.5 V / m) in the angles between 90°-270°, returning

to recover a maximum value (12.16 V / m) at 315°. As can be seen, these values, transmitted by the XArray equipment, decline significantly with distance, reaching values of 7.9 V / m and 5.3 V / m at the angles at a distance of 100 cm, 0° and 45°, respectively, and 1.5 V / m at angles between 90°-270°. The lowest values were recorded at 3 meters from the emitter, with levels of 1.49 V / m and 0.71 V / m in the 0° and 45° angles, respectively, and 0.25 V / m in the angles between 90°-270°. Table 8 presents E-field strength in the orientation of maximum radiation from the tested device in function of the distance.

In Fig. 18 and Fig. 19 are presented two graphs of the E-field strength in the orientation of maximum radiation from the tested device in function of the distance. Fig 18 shows the radiation pattern of the XArray evaluated. Fig.19 presents E field calculated at different distances.

3) 2D GRAPHIC REPRESENTATION

Fig. 9 presents points of measurement marked. In each measurement point the antenna has been oriented to detect the maximum value of the E-field at 100 cm and 170 cm heights above the ground as was presented in [45]. In these locations,
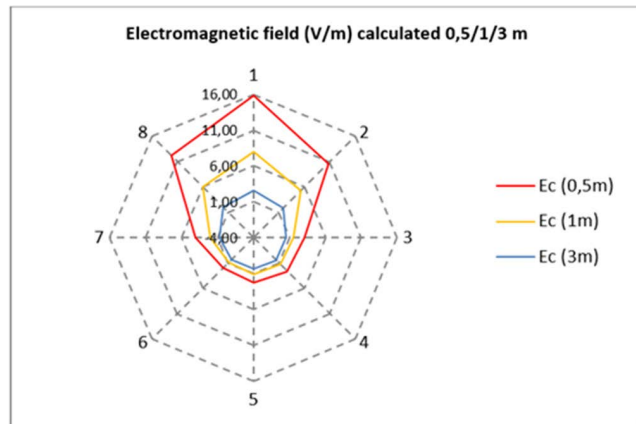
FIGURE 19. Radiation pattern of the XArray spectrum evaluation and calculated E-field.

TABLE 8. XArray maximum electric field values in different units at 300 cm.

Azimut	ERP dBm	ERP W	Ec(3m) V/m	Ec(1m) V/m	Ec(0.5m) V/m	Em(3m) dBuV/m	Em(3m) V/m
0	32.58	1.81	2.65	7.94	15.88	123.46	1.49
45	29.13	0.82	1.78	5.34	10.68	117.03	0.71
90	18.24	0.07	0.51	1.52	3.05	107.60	0.24
135	17.04	0.05	0.44	1.33	2.65	105.11	0.18
180	15.92	0.04	0.39	1.17	2.33	103.52	0.15
225	14.20	0.03	0.32	0.96	1.91	101.58	0.12
270	20.84	0.12	0.69	2.06	4.11	108.63	0.27
315	30.26	1.06	2.03	6.08	12.16	118.06	0.80

the values of the E-field were collected and registered. The 2D contour maps of the data set, and the location of the radiation source are presented graphically in Fig. 20 and Fig. 21. Analyzing the graphs, characteristic features of the experimental results are remarkable. This specific rise of the electric field intensity matches the position where there is a greater exposure to the EM radiation than the other points of the scenario under test.

Another aspect that has been studied is the variation in results between 100 cm and 170 cm heights above the floor, as the higher are more exposed and closer to the radiation sources. After measuring and calculating the EM conditions, it is crucial to carry out a study of the results and to check whether the obtained values are under the thresholds of the recommended exposure levels [19].

IV. DISCUSSION

A. ICNIRP COMPARISON WITH MAXIMUM TRANSMITTED POWER AND LIMITATIONS

European regulations regarding human exposure to EMF include requirements on safety of workers, general public and vulnerable populations, focused significantly on the safety of users of AIMD, including those exposed in assisted in the context of health environments. The exposure limits set by the Recommendation 1999/519/EC (general public) and
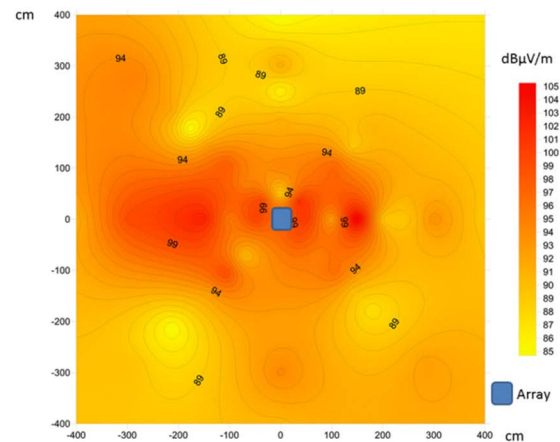

FIGURE 20. 2D Contour maps of the experimental values of the E-field in dBμV/m in 100 cm high on XArray.
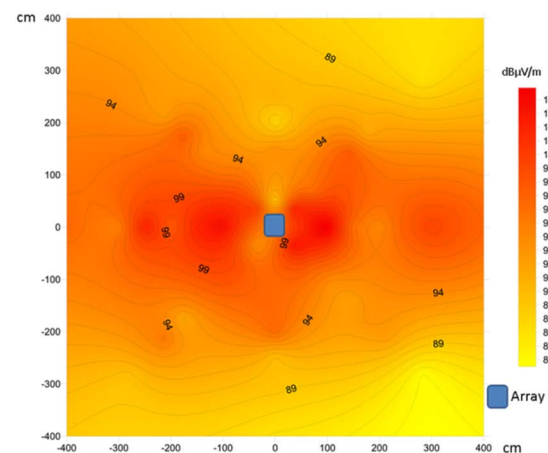

FIGURE 21. 2D Contour maps of the experimental values of the E-field in dBμV/m in 170 cm high, on XArray.

Directive 2013/35/EU (workers) are based on the electric and magnetic field reference levels provided for an evaluation of the whole body EM exposure by the International Commission of Non-ionizing Radiation Protection (in considered case of exposure to EMF at 865-868 MHz frequency, E and H of approximately 90 V/m and 0.24 A/m or 40 V/m and 0.11 A/m, for workers or general public exposure, respectively) [31]. The ICNIRP published new guidelines in 2020 (including additional provisions on the evaluation of the localised EM exposure); these have not been included in any directive yet [19]. The use of UHF-RFID readers can also alter EM conditions affecting the safety of vulnerable population. Article 15 of the Occupational Health and Safety Framework Directive 89/391/EEC [60], requires that "Particularly sensitive risk groups must be protected against the dangers that specifically affect them". Factors of AIMD use that influence the probability of EM interferences in its functioning and related to health and safety hazards to its users include: EMF frequency and exposure level and duration, the EM performance of the AIMD, its settings and the method of implantation, as well as the health status of a particular user of AIMD. In this sense, some limitations about

updated guidelines are observed. They have been developed keeping the view that it's only necessary to protect against the thermal (heating) effects of exposure and not that harmful effects occur at much lower levels. Secondly, ICNIRP has assumed that exposure measurements can be averaged over a period of time. This is not necessarily the case, and the impact of short, intense exposure needs to be considered. So, too, do the characteristics of the signal (polarization, pulsing and modulation, for example) that affect how the body responds to exposure. By taking into account only the mean values of an exposure, the Guidelines underestimate its risk.

B. MEASUREMENTS RESULTS

As previously explained in detail in Section II, an EMF campaign of measurements was designed and performed within different types over fixed RFID readers. In Fig. 18 and Fig. 19, the E-field measurement results for two different protocols are depicted. The obtained EM levels are also under the security threshold stated by ICNIRP-20 [19]. This means that E-field levels in healthcare are apparently safe according to the health and safety requirements concerning the exposure of patients, workers and the general public to the risks derived from electromagnetic fields.

Some concern involves the possibility of interference with medical devices. The International Electrotechnical Commission (IEC) Standard IEC 60601-1-2 [61] sets a minimum immunity level of 129.54 dBμV/m. Examining experimental results, the maximum value of the E-field is much lower than the 129.54 dBμV/m. The emissions of this equipment under study are not continuous, but operate with a signal pattern in the form of very short duration pulses and the field levels decline significantly with distance.

In real conditions, the exposure to the emissions of the studied equipment will be considered occupational, with the user workers being exposed in a non-continuous and non-homogeneous way. In case of occupational safety assessment of exposures in the frequency range of interest in the present case, the criteria is established in Directive 2013/35/EU of the European Parliament and of the Council on the minimum health and safety requirements concerning the exposure of workers to the risks derived from physical agents (electromagnetic fields) [31]. This legal text establishes exposure limits for the protection of staff health from the immediate effects of short exposures to non-ionizing radiation. The analysis of the data obtained reveals that of the maximum levels of E-field emitted by the equipment under test, the highest would be far from the Action Level established by the standard (AL = 158.92 dBuV/m).

In the vicinity of these equipment, general public can be present and in this case, their exposure levels would be regulated by [51] which establishes a Reference Level RL = 152.15 dBμV/m. In this case, the highest maximum levels are also under the RL, and also correspond to the RFID transmitter (approx. 1/3 RL) and in-situ experimental EMF evaluation needs to be performed using professional measurement devices and ensuring immunity of the measurement

device to EM influence from other frequency bands. As in the real measurements, the same transmitter locations have been considered in the simulations to compare the obtained results with the measured ones. Therefore, the comparison with current legal exposure limits has been presented, verifying that, for all cases, E-field levels were below the aforementioned limits. These results and the proposed simulation methodology, can aid in an adequate assessment of EMF exposure recommendations and limits, for this fixed readers.

V. CONCLUSION

A holistic, immediate and accurate vision that can help to avoid EM interferences on electro medical equipment, and supervise the exposure to EM fields of the workers, the patients and the general public may be obtained by the computation of 2D contour maps of EMF presented, in this case in a healthcare center. The analysis and study of the EM conditions in a healthcare environment using 2D contour maps could be helpful for the following purposes:

- Detection of over-exposed points to electromagnetic radiation and areas with greater absorption levels
- To be avoided potential harm to patients due to the interference on electromedical equipment and on implantable personal devices.
- To monitor appropriately the exposure to electromagnetic fields of healthcare workers, patients and the general public.
- To achieve emission levels under the recommended thresholds, but enough levels to guarantee a high quality service of wireless communication systems.
- To plan and design new high-tech healthcare centers.

In accordance with all of the above, and considering the mean value of instantaneous emissions, the actual operating distance and the fact that the exposures would be infrequent, it can be concluded that there is no risk that the staff using the equipment evaluated or the public that may be found nearby suffers thermal damage owing to exposure to the sort of emissions recorded in this study.

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