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Measurements of intermediate-frequency electric and magnetic fields in households

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ABSTRACT

Historically, assessment of human exposure to electric and magnetic fields has focused on the extremely-low-frequency (ELF) and radiofrequency (RF) ranges. However, research on the typically emitted fields in the intermediate-frequency (IF) range (300 Hz to 1 MHz) as well as potential effects of IF fields on the human body remains limited, although the range of household appliances with electrical components working in the IF range has grown significantly (e.g., induction cookers and compact fluorescent lighting). In this study, an extensive measurement survey was performed on the levels of electric and magnetic fields in the IF range typically present in residences as well as emitted by a wide range of household appliances under real-life circumstances. Using spot measurements, residential IF field levels were found to be generally low, while the use of certain appliances at close distance (20 cm) may result in a relatively high exposure. Overall, appliance emissions contained either harmonic signals, with fundamental frequencies between 6 kHz and 300 kHz, which were sometimes accompanied by regions in the IF spectrum of rather noisy, elevated field strengths, or much more capricious spectra, dominated by 50 Hz harmonics emanating far in the IF domain. The maximum peak field strengths recorded at 20 cm were 41.5 V/m and 2.7 A/m, both from induction cookers. Finally, none of the appliance emissions in the IF range exceeded the exposure summation rules recommended by the International Commission on Non-Ionizing Radiation Protection guidelines and the International Electrotechnical Commission (IEC 62233) standard at 20 cm and beyond (maximum exposure quotients EQ_E 1.0 and $_EQ_H$ 0.13).

1. Introduction

Electric appliances have become almost indispensable in our households. Connection to a power supply and use of electricity, however, leads to the emission of electric (EF) and magnetic fields (MF). To safeguard the general public from possible adverse health effects (such as electrostimulation) caused by EF and MF at frequencies typical for household appliances (i.e., lower than 1 MHz), their fields are subject to limits based on recommendations by international bodies such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 2010) and the Institute of Electrical and Electronics Engineers (IEEE) International Committee on Electromagnetic Safety (ICES) (IEEE, 2006). Technical standardisation bodies such as the International Electrotechnical Commission (IEC) and the European Committee for Electrotechnical Standardization (CENELEC) use these guidelines as the basis for specific emission standards which enable manufacturers to demonstrate that their products are safe.

Historically, measurements of electromagnetic exposure from household appliances (e.g., Addari, 1994; Ainsbury et al., 2005; EPA, 1992; Karipidis and Martin, 2005; Leitgeb et al., 2008a, 2008b) and in residential environments (e.g., Addari, 1994; Preece et al., 1997;

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UKCCS, 2000; Tomitsch and Dechant, 2015) have focused on the *extremely-low-frequency* (ELF) range, between 1 Hz and 300 Hz, as the mains frequency (i.e., 50 Hz or 60 Hz) posed the dominant contribution. However, while the range of household appliances with electrical components working in the *intermediate-frequency* (IF) range (300 Hz to 1 MHz) has grown significantly in recent years (e.g., induction cookers and compact fluorescent lighting), there is still only limited information available on either the typical strength of the IF fields emitted by household appliances and on the typical human exposure to IF fields at home (Gajšek et al., 2016; Litvak et al., 2002; WHO, 2005).

Previous research on IF field emitting sources has tended to focus either on occupational sources (Aerts et al., 2014; Floderus et al., 2002; Joseph et al., 2012a, 2012b; Liljestrand, 2003; Nelson and Ji, 1999; Van den Bossche et al., 2015; VMBG, 2003; Wilén, 2010) or on non-residential appliances such as electronic article surveillance (EAS) systems (Harris et al., 2000; Joseph et al., 2012c; Kang and Gandhi, 2003; Martínez-Búrdalo et al., 2010; Roivainen et al., 2014; Trulsson et al., 2007), smartboards, and touch screens (Van den Bossche et al., 2015). Research on residential IF sources, on the other hand, is limited. There has been some research on induction cookers (Christ et al., 2012; Kos et al., 2011; Mantiply, 1997; Stuchley and Lecuyer, 1987), energy saving lamps (Bakos et al., 2010; Nadakuduti et al., 2012; Van den Bossche et al., 2015), portable hearing units (Van den Bossche et al., 2015), plasma balls (Alanko et al., 2011), and magnetic-field measurements were performed in a brief survey (Kurokawa et al., 2004). However, no surveys have yet been performed that address specifically typical IF field levels in the home.

In this paper, the results of a residential IF field emission survey spanning 42 residences in three European countries (Belgium, Slovenia, and the United Kingdom (UK)) are presented. Typical field levels in the properties were assessed by measurements in the middle of the most-frequented rooms (living room, kitchen, and bedroom), as reported by residents. The IF fields emitted from a wide range of household appliances were also investigated through measurements as a function of distance performed on 279 appliances, operating under real-life circumstances. This study, which focuses on exposure characterisation in everyday circumstances for epidemiological purposes, substantially extends current knowledge of typical IF fields in people's homes.

2. Materials and methods

2.1. Measurement equipment

To characterize the IF field levels in residences from household appliances, three measuring devices were used: a compact handheld meter (NFA-1000, Gigahertz Solutions, Langenzenn, Germany) and two computer-operated narrowband probes (EHP-50 and EHP-200, Narda Safety Test Solutions, Milan, Italy).

The NFA-1000 is able to (separately) measure the environmental magnetic- (H, in A/m) and the electric-field strength (E, in V/m) in the frequency range between 5 Hz and 1 MHz, with dynamic measurement ranges of 0.8 mA/m to 1.6 A/m and 0.1 V/m to 2 kV/m, respectively. Measurements can be performed wideband (i.e., over the whole frequency range) as well as narrowband (i.e., in separate frequency bands: 16.7 Hz, 50 Hz, even harmonics up to 250 Hz, uneven harmonics up to 250 Hz, the remainder of frequencies below 2 kHz, and the frequency range between 2 kHz and 1 MHz).

The EHP-50 (with dynamic measurement ranges of 0.005 V/m to 100 kV/m (E) and 0.24 mA/m to 8 kA/m (H)) and EHP-200 (0.02–1000 V/m (E) and 0.6 mA/m–300 A/m (H)) probes were used to acquire EF and MF spectral information in their respective frequency ranges of 5 Hz to 100 kHz and 9 kHz to 30 MHz. When taking into account linearity, isotropy and frequency response, the expanded uncertainty (k=2) for the EHP probes was 8% and 15%, respectively. Assuming a conservative uncertainty of 10 °C in temperature and 10% in humidity, the expanded uncertainty respectively becomes 10% and 16%. Furthermore, to mitigate the uncertainty due to the spatial displacement of the X-, Y-, and Z-sensors in the EHP probes (which can amount to 28% according to Nadakuduti et al. (2012)), the top of the probe was always directed towards the appliance under assessment (Christ et al., 2012).

The EHP probes have been designed to have no or minimum perturbation of the fields that are being measured, and the tripod used to hold the probes was made of low permittivity materials. Also, the EHP probes were connected to a laptop via an optical cable, allowing measurements to be made several metres away. Thus, perturbation of the electric field was kept to a minimum.

To obtain a complete sweep of the frequency range relevant to the study, measurements were performed using the 2 kHz and 100 kHz measurement bands of the EHP-50 (i.e., 5 Hz to 2 kHz and 1 kHz to 100 kHz ranges, respectively) and also in the frequency range 9 kHz to 400 kHz (further called 400 kHz band) with the EHP-200, at a resolution bandwidth of 3 kHz. For each measurement, the maximum-hold setting was used, i.e., the maximum values were retained during a time interval until the reading stabilized (roughly 30 s). The 2 kHz band was necessary to capture the 300 Hz to 1 kHz range, but the results were mainly used for illustration.

2.2. Measurement procedure

2.2.1. Selection of residences

In total, 42 residences were investigated; 11 in Belgium, 16 in Slovenia, and 15 in the UK. This resulted in the measurement of the level and composition of environmental IF fields in 121 rooms and of 279 household appliances. The residences were from a convenience sample, and included detached, semi-detached and attached houses as well as apartments. The residents were interviewed to obtain information related to the time spent in different rooms and the use of electrical appliances found in the residence.

2.2.2. Spectral survey of the residence

To obtain a general idea of the strength of environmental IF fields in the property, two spot measurements were performed in a number of rooms – usually three, and ideally the ones in which the residents reported spending most of their time – one when the room was in 'hibernation mode' (i.e., the normal state of the room when no one is at home) and one during 'maximum living mode' (i.e., all EMF sources – lights, displays, kitchen appliances, etc. – normally in the room switched on, as far as this was feasible). During both usage modes, the ELF and IF fields in the room were characterised using the EHP probes, secured to a tripod positioned in the middle of the room, at 1.5 m above the floor.

2.2.3. Characterisation of IF emitting appliances

By measuring E and H in the 2 kHz to 1 MHz band solely, the NFA-1000 m enabled the quick identification of IF field emitting household appliances. When an appliance was identified as an IF source, the emitted IF fields were subsequently characterised with the EHP probes while the appliance was operated at settings typical for the residents. The probe was positioned in front of the face of the appliance closest to the user, or, for appliances with no preferential orientation, in front of the face where the highest exposure was detected. All measurements were taken at mid-height of the appliance, except for lighting sources, for which the measurements were performed in the direction of use (i.e., down when the lighting source was hanging from the ceiling and sideways when standing).

In the following, the measuring distance was defined as 'the distance between the surface of the appliance and the closest point of the sensor surface' (International Electrotechnical Commission (IEC), 2005). Although some previous studies opted to focus on the exposure