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PRINCIPLES AND METHODS OF MEASURING ENVIRONMENTAL LEVELS OF HIGH-FREQUENCY ELECTROMAGNETIC FIELDS

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Abstract. The progress of communication technology led to large-scale use of wireless devices both in occupational environment and in private life. Consequently, human exposure to high-frequency electromagnetic fields is increasing and it is necessary to assess it. An important step in exposure assessment consists in measuring electromagnetic field levels at workplaces, in public areas or in residential buildings. To help understanding the requirements concerning the process of measuring field levels, we present some knowledge in this domain. Principles regarding field characterization and measurement are discussed. Basic knowledge on sensors, probes and instruments adequate for field measurement in the high-frequency range are also presented. In the last part of this paper, we focused on main types of instruments, main categories of measuring methods and some general procedure for accurate measurement of high-frequency electromagnetic fields.
Key words: electromagnetic fields, exposure assessment, communication technology

Rezumat. Progresul înregistrat de tehnologia comunicațiilor a condus la utilizarea pe scară largă a dispozitivelor de comunicare fără fir, atât în mediul ocupațional, cât şi în viața privată. În consecință, expunerea umană la câmpuri electromagnetice de înaltă frecvență este în creştere şi este necesar să fie evaluată. Un pas important în evaluarea expunerii constă în măsurarea nivelelor câmpurilor electromagnetice la locurile de muncă, în spații publice sau în locuințe. Pentru a ajuta înțelegerea necesităților referitoare la procesul măsurării nivelelor de câmp, prezentăm unele noțiuni în acest domeniu. Sunt discutate principiile privind caracterizarea şi măsurarea câmpurilor electromagnetice. De asemenea, sunt prezentate noțiuni de bază despre senzori, sonde şi instrumente adecvate măsurării câmpurilor electromagnetice în domeniul de înaltă frecvență. În ultima parte a acestei lucrări, ne-am focalizat asupra principalelor tipuri de instrumente, a principalelor categorii de metode de măsură şi a unor proceduri generale pentru măsurări de acuratețe a câmpurilor electromagnetice de înaltă frecvență.
Key words: cimpuri electromagnetice, evaluarea expunerii, tehnologia comunicatiilor

INTRODUCTION

In the domain of both, public health and occupational health, the exposure to high-frequency (HF) electromagnetic fields (EMF) represents a very important component of the total human exposure to electromagnetic fields. Actually, a large part of the electromagnetic spectrum lies in the HF range. Examples of HF-EMF are radiofrequency (RF) fields and microwave (MW).

Generally, in contrast to other physical agents, electromagnetic fields can not be perceived by human senses. To emphasize the presence of electromagnetic fields in the environment, special equipment is needed (1, 2, 3). In the case of RF and MW fields, the equipment is divided in two categories: alert devices and measuring instruments. Alert devices are small, compact, wearable and they are designed to indicate by an alarm sound when the level of the field exceeds a preset value. Measuring instruments can incorporate an alarm function, but they are mainly designed to accurately measure the field level, to indicate it on a display and/or to record it. We present some information on principles concerning field characterization, measurement of HF-EMF and we describe the main categories of methods used to measure environmental level of RF and MW fields.

Principles of field characterization

High-frequency electromagnetic fields are mainly described by means of three vectors: electric field strength *E*, magnetic field strength *H* and power density *S*, also called Poynting vector (2, 4, 5). The first two vectors, electric and magnetic field strengths, are adequate quantities to characterize any HF-EMF. On the contrary, power density characterizes only the radiation of fields and it is not appropriate for quantifying the magnitude of non-radiating fields.

Far away from the source, there is the so called far-field region where the field is propagating in nature. The field it is described by the spherical model of propagation but, in a limited region of space it can be approximated by plane wave model. In the far-field region, there is a simple relation connecting the magnitudes of the three field vectors:

$$S = E \bullet H \qquad (1)$$

Moreover, in the far-field region, there is a constant ratio between the two field strength, E/H, called free-space impedance Z_0:

$$Z_0 = \frac{E}{H} = 377\ \Omega \qquad (2)$$

Consequently, measuring one of the field strengths, the other one can be simply calculated as well as the power density.

Close to the source, the field is called near-field. In this region, the field is more non-propagating in nature, i.e. it is, mainly, a reactive field. The above equations are not valid in the near-field. Power density is not useful to characterize the HF field given that the reactive part of the field is significant or even dominant (6, 7).

Consequently, both electric and magnetic field strengths have to be measured and reported (8).

Sensors and instruments

In principle, an EMF measuring instrument consists of a sensor, a detector and a processing and display device.

The sensor (pick-up device) is the core of the measuring instrument given that its role is to interact with the field and extract information about the level and other characteristics of the field. The field induces a voltage, a current or causes a change of sensor properties (geometric, mechanic, electric or optic properties) which is converted into an electric signal by means of a specific effect (piezoelectricity, Kerr effect, heating of junctions, etc.) (2, 9).

The detector is the element that transforms the high frequency electric signal provided by the sensor into a continuous or low-frequency voltage depending on the absence or presence of the modulation. The most common detectors are the detector diode and the thermocouple.

Practically, HF-EMF measuring instruments consist of a probe, a connecting cable and a monitor. There also exist monolithic instruments where all the components are included in a single unit. Some other instruments do not use a connecting cable, the probe being directly inserted in the monitor. The main advantage of the first and last kind of instruments (non-monolithic ones) is that they can use various probes with various characteristics provided that the probes are compatible with the instrument. Another advantage of the non-monolithic instruments is that the field in the measuring point is less perturbed by the operator of the instrument as far as there is a longer distance between the sensor and the hand of the operator holding the monitor.

The probe contains one or more sensors, it may also include the detector and, in some cases, it contains some processing circuits. In other instruments, e.g. instruments with spectral analysis facility, the detector as well as the processing circuits are included in the monitor.

Probes containing only one sensor are anisotropic i.e. they are very directional. To measure the field level, the probe is aligned with the sensor parallel to the field direction. An alternative solution is to carry out measurements on three directions orthogonal one to each other (x, y and z in the Cartesian system of coordinates) and compute the total field value:

$$E = \sqrt{E_x^2 + E_y^2 + E_z^2} \quad (3)$$

$$H = \sqrt{H_x^2 + H_y^2 + H_z^2} \quad (4)$$

On the contrary, isotropic probes have neither to be aligned to field direction nor to carry out three measurements on Cartesian axes.

Depending on which field component the sensor interacts with, the HF probes are classified as: electric field probes and magnetic field probes (2, 3, 9).

As sensors for the electric field component, the most used are the short monopoles (fig.1) or short dipoles (fig.2). Their dimension l has to be much smaller than the shortest wavelength λ corresponding to the highest measured frequency.

For the magnetic field, much used are the loop antenna or coils with a few coilings (fig.3). All these sensors have dimensions much smaller than the shortest wavelength of the fields to be measured.

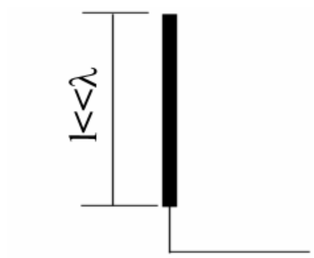

Fig. 1. Electrically short monopole

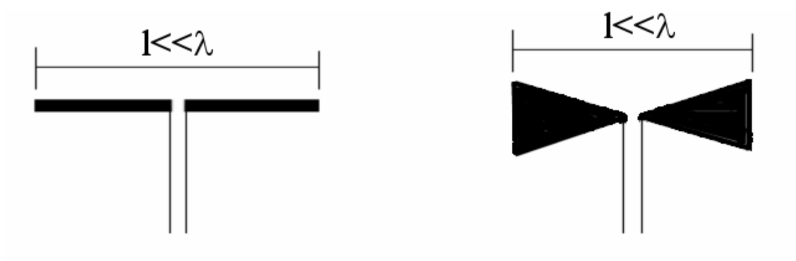

Fig. 2. Electrically short dipoles

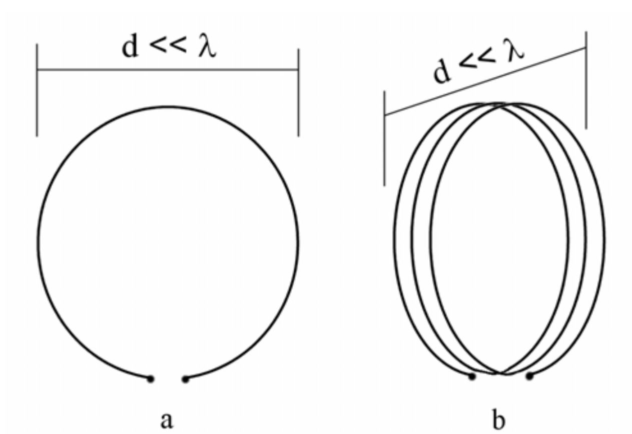

Fig. 3. Loop antenna (a) and a few turns coil (b).

In addition to electrically-short sensors, various antennas can be used as electric or magnetic field sensors. Examples of such sensors are: half-wave dipoles, rod antennas, Yagi antennas, biconical antennas, Horn antennas. Moreover, modern sensors have been developed on other principles of operation (10), including sensors that measure both electric and magnetic fields (11).

Methods and techniques of measurement

To measure the field level, the signal given by the probe has to be applied to the monitor. While the nature of the field and the total frequency range is given by the probe, mainly by the sensor construction, the type of the measurement, meaning the frequency band processed to provide the output value is given by the monitor design. Concerning the processed frequency band, measuring instruments are classified as:

- broadband instruments;
- narrow band instruments;
- quasi-narrowband instruments.

Broadband instruments simultaneously respond to all the frequencies within the frequency range. These instruments can rapidly measure the total field level, but they can neither measure the frequency of the fields, nor separate the contributions of the fields with different frequencies to the total field level.

Narrowband instruments are tuned before measuring and they scan the frequency range of interest with larger or smaller steps. They also measure the frequency of the fields and determine the contributions of all the frequencies to the total field level.

The third type, quasi-narrowband instruments have basically a relatively broadband response, but they are equipped with filters that limit the response (sensitivity) to a relatively narrow frequency range. An example of quasi-narrowband instrument is a power-meter connected to a calibrated antenna.

Although there were enumerated three kinds of instruments, the quasi-narrowband instruments can be assimilated to narrowband technique. Thereby, HF-EMF measurement methods are classified in two main categories: broadband and narrowband.

When selecting suitable measurement methods and instruments (2, 3, 8) the following factors are taken into account:

- characteristics of the sources;
- the presence of more the one sources;
- frequencies;
- estimated field level at the measuring points;
- action values in the frequency domain of interest;
- the necessity to determine each source contribution.

Broadband methods can be used when the frequencies of the sources are known, at least for the relevant frequencies corresponding to highest level fields and the reference levels are equal for all relevant fields. Usually, a field of a specific frequency is considered relevant if it is the dominant one or it is lower than the dominant field with no more than 10 dB (12) or, to be accurate enough in the case of most complex exposure situations, lower with no more than 15…20 dB (7). Broadband methods are also used when the frequencies of sources are not known, but it is known that all the frequencies are within a frequency range for which the exposure standard sets a constant reference level.

Broadband methods and instruments can be used even when the reference levels for present frequencies are different, but only if shaped probes (frequency-weighted response according to the exposure standard) are employed. However, in the last case there is not a true measurement, but only a test of compliance with exposure standard. The use of shaped probes does not provide the result of measurement as absolute values of the field, but only as a percentage of the reference level. When multiple frequency fields are present, given that the result is a summation of ratios measured/reference levels, it is not possible to calculate the total field level.

Narrowband methods can be used in any of above mentioned cases. They are needed to measure the value of total field level when reference levels are different for the existing frequencies. Narrowband methods are also used when it is necessary to determine the frequency or when the level of field generated by each source has to be known. A special application of narrowband methods is in the case of determining the level of fields generated by communication systems when measurement of one or more channels is required. An example of such a case is represented by GSM mobile phone system (13).

Practical considerations

Before starting measurements, several preceding steps should be taken into account (8). First, it is important to get information about the characteristics of the RF sources and about the exposure situations. This information is to be used to decide what quantities have to be measured, to estimate the characteristics of the exposure field, including the expected field level at the measuring points. All this information and the evaluation are necessary for an adequate selection of the instrument, of the set of probes to be used and for operator protection against exposure to high-level fields.

Information about the RF source concerns mainly:

- frequencies;
- emitted power;
- polarization (orientation of E field);
- modulation characteristics;
- antenna characteristics.

Information about the exposure situation focuses on:

- number of sources;
- distance from the source;
- existence of any scattering objects;
- orientation of field vectors with respect to irradiated person.

First measurements will be carried out at distances away from the source where it is estimated there is no risk for both operator and measuring equipment. Provided that the first measurement confirms there is no risk, further investigation getting closer to the source is allowed.

HF-EMF measurements will be carried out in all points were significant levels are estimated and human presence could occur. Field levels will be also measured in the places were people are often present or in places where high levels are expected, e.g. in the proximity of the sources.

In the case of occupational public, all workplaces assumed to involve exposure to HF-EMF will be investigated. The field levels will be measured in the case of typical work regime of installations and, also for the case that can generate the maximum exposure of workers.

CONCLUSIONS

- The problem of measuring high-frequency electromagnetic fields is quite sophisticated, especially in some cases.
- A good knowledge of at least basic knowledge in electromagnetism is needed to understand what kind of exposure could occur from specific sources and what quantities should be measured. Knowledge of measurement principles and of sensor operation is also very important.
- The operator of the equipment should be familiar with the procedures concerning estimation of expected field level and evaluation of exposure situation.
- A great diversity of instruments and probes are available and the accuracy of measurement depends on the right choice of employed equipment.
- A good practice is also essential to minimize errors and to provide reliable results.

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