MEASUREMENT OF MICROWAVE RADIATION FROM ROTATING RADAR ANTENNAS AND PROPOSALS FOR LIMITING EXPOSURE TO PULSE-MODULATED RADIATION IN GENERAL PUBLIC AND OCCUPATIONAL

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1. INTRODUCTION

Numerous investigations, performed in recent years, have confirmed occurrence of various biological effects, which have been evoked by pulsed microwave radiation in humans and animals. In such exposures, e.g. from radars, the energy may reach very high values of power density in peak, at relatively low levels of power density averaged in time. This is because the pulse duration (t_p) of the radar radiation is hundreds times shorter than pulse repetition (T_p), thus an average value of power density is hundreds times lower than a peak value of the radiation.

We should consider not only evidence that the energy radiated from radar could have an enormous value (kW/m^2 or even MW/m^2) in peak but also that the radiation from radar is changeable in space, because of mechanically or electronically driven antenna systems. Due to the rotation of radar antenna, the measurement point "is exposed" to pulse modulated MW radiation periodically within a very short time (e.g. tens of msec), which strongly depends on the width of a main lobe and rotation speed of an antenna. It is easy to guess that an average value of power density (averaged over pulse repetition and over a period of antenna rotation) is additionally lower.

Up to now no one has proved that the relationship between a dose of radiation and biological effects has the same correlation function for weak field as well as for a very strong field in peak. In addition, it is necessary to underline that in some articles the authors pointed out that pulse modulated fields could cause biological effects, although no effects appear when the radiation is CW type at the same average value of power density [1, 2, 3, 4]. In the recent article Lai at al. [5] have proved that pulse MW (2450 MHz) cause behavioral effect – investigated rats learned slower to locate the platform – even when the averaged value of power density flux was relatively low – S_{av} = 20 W/m^2 (S_{peak} = 20 kW/m^2).

2. Measurement and evaluation of the exposure of microwave radiation from radars

Radars have different type of scan space and different patterns of antenna characteristics because of various purposes they have been made for. Thus, EM energy emitted by radar changes direction in azimuth and elevation planes. Thus the radar radiation of the EM field appears at the measurement point periodically within a very short time (e.g. tens of msec), which strongly depends on the width of the main lobe and scan sector of the antenna. Additionally, this MW energy emitted from radars, due to the rapidly changeable field patterns, is “seen” in a measurement point in the form of a very short pulses (2 ÷ 20 μsek each) during the whole period of scan space.

In such situation there is a need to measure (characterize) 3 parameters of the power density of the radar radiation (Fig. 1):

S_{av} – the averaged value of the power density (this is in fact averaged value over any period of time, for example over 6 min or/and the period of antenna rotation),

$S_{pp\ av}$ - the averaged value over pulsed repetition (this is a situation when an antenna is stopped),

S_{peak} – peak value of the power density.

Fig.1. Exposure pattern from any of the radar types in a measurement point during space scan.

Thus an important problem arises – which value is the best parameter to characterize the radar radiation. According to most Western standards the MW radiation emitted by radars should be averaged over any 6 min (S_{av}). However, there is a great obstacle in realization this value this is because main lobes of rotating radar antennas are very narrow. Due to the rapidly changeable field patterns, there is no commercially available RF meter which can measure correctly this field. Some of the meters can measure pulse modulated MW radiation but they need relatively long period for measuring train pulses to reach the averaged value, so they need to stop an antenna during measurement. Moreover, the difficulties with measuring EM fields increase in case of radars with modern generation of 3D antennas. In this case, the movements of the main lobe are more complex (the lobe changes its position in horizontal as well as vertical position). The simple way to assess exposure from radar which periodically scan space is to stop the antenna and measure the maximum value of the main lobe, averaged over pulse repetition ($S_{pp\ av}$). From this, the average value over a period of scan space (S_{av}) can be calculated taking into account the parameters of the radiation pattern of the antenna.

3. General conditions for proposed safety limits for pulse-modulated radiation

The proposals of safety limits both for general public and occupational exposures have been based on the verified literature data. Unfortunately, confirmed data for humans were published only for few frequencies, mostly for 2,45 GHz. The proposed safety limits of peak-power level exposure were designed for microwave frequency e.g. from 0,1 ÷ 300 GHz, where you can find different radars working. Nevertheless, the whole microwave spectrum has been divided into 3 parts: 0,1 ÷ 3 GHz, 3 ÷ 10 GHz and 10 ÷ 300 GHz, according to the Polish safety limits of EMF exposure for workers [6]. Each range of frequency is specific for characteristic of EMF sources and for biological interaction with EMF exposure.

4. A proposal of safety limits for pulse power density in general public

A proposal of safety limits for pulse-power density of EM radiation in general public has been mainly designed to protect humans against microwave auditory effects.
In addition, the above hearing phenomenon occurs with nonauditory effects, like stress and annoying. Even the investigators who underlined that there exist doubts as to whether or not this hearing effect is a hazard, suggest that it is reasonable to establish the power density limits of maximum peak-pulse value (S_{peak}) for general public and base the limits on hearing effects.
The microwave auditory phenomenon has been recognised as one of the most interesting biological effects of microwave (MW) radiation. Short pulses of microwave radiation produce audible sound into heads of humans and animals. The energy of MW radiation is converted into heat and produces a small ($\approx 10^{-6}$ °C/s) but rapid rise (≈10 μs) of temperature. This rise of temperature generates rapid thermoelastic expansion of tissues in the head, which launches an acoustic wave of pressure. The auditory phenomenon evokes similar effects as sound exposure.

Unfortunately, the confirmed data for humans were published only for few frequencies, mostly for 2,45 GHz. On account of this the value of peak-power density of $S_{peak-max}$= 13 kW/m^2, which evokes the auditory effects in 2,45 GHz in human's head is taken as a base for designing the safety limits. The value of $S_{peak-max}$ = 13 kW/m^2, was derived from the described in the literature threshold of specific absorption (SA) per pulse.

① Frequency range 0,1 ÷ 3 GHz

In this frequency range it has been proved that microwave hearing is dependent on the energy content of pulses that are shorter than 30 μs and on the peak-power for pulses longer than 50 μs. Thus, the values of safety limits for pulse-power density ($S_{peak-max}$) have been calculated on the base of SAR vs. frequency. The formulas for SAR have been adapted taking into account formulas given in "Dosimetry Handbook". Calculations have been realised for equivalent spherical model of the human's head. As a result, the function of peak-power density vs. frequency one obtains:

$$\mathbf{S_{peak-max} = (2{,}5\ f_{[GHz]} + 6{,}7)\ kW/m^2}$$

② Frequency range 3 ÷ 10 GHz

This frequency range is a passing range, which joins the value of $S_{peak-max}$ for 3 GHz (in the frequency range ①) with $S_{peak-max}$ for 10 GHz (in the range ③)

$$\mathbf{S_{peak-max} = (16{,}5\ f_{[GHz]} - 35{,}3)\ kW/m^2}$$

③ Frequency range 10 ÷ 300 GHz

In this frequency range there is no confirmed data of auditory effects for humans. The only available data have been described for cats. The depth of penetration into tissues is small and it is likely that only small part of incident energy could induce hearing effects into head. Comparing available literature data for auditory effects for cats in the X band (8 ÷ 12 GHz), it is easy to notice that those effects can be generated but the power density must be 10 times greater than for 2,45 GHz. Thus, according to the above considerations one could establish the value of power density limit for humans, according the same rule, 10 times greater than in 2,45 GHz. Finally in this frequency range:

$$\mathbf{S_{peak-max} = 130\ kW/m^2}$$

In the frequency above 50 GHz, the limit value of power density is only speculative (doted line in Fig.2).

Fig.2. A proposal of safety limits for pulse-power density of EM radiation in general public.

5. A proposal of safety limits for pulse power density in occupational exposures

In the case of safety limits in occupational exposures it is easy to notice that value of power density based on the auditory phenomenon is “too protective”. This is because in the real situation e.g. near radar antennas, the exposure conditions differ considerably from these which were taken in laboratories to develop the auditory effects. Taking into account the maximum energy in peak, which is necessary to evoke the hearing effects, one ought to underline that in laboratories all peaks of power density had the same value during experiment. In the real situation, the values of pulses vary, depending on the rotation of main lobes of antennas. Thus, human head is not exposed to the same value of peak-power density, but only during a short period of time, Fig.1. This means that the exposure near radars is much lower than developed in the experiments.

Taking into account the above considerations and that workers could be exposed to pulsed MW radiation only during an 8 hours shift, we have designed limits for occupational exposure based on other biological effects, e.g. on behavioral effects. In this case the “safety coefficient” (1 : 10) must be considered.

① <u>Frequency range 0,1 ÷ 3 GHz</u>

In this frequency range the value of peak-power density that evokes the behavioral effects has been established as 500 kW/m^2. Taking into account the safety factor 1:10 one obtains:

$$\mathbf{S_{peak\text{-}max} = 50\ kW/m^2}$$

② <u>Frequency range 3 ÷ 10 GHz</u>

This frequency range is a passing range, which joins the value of $S_{peak\text{-}max}$ for 3 GHz (in the frequency range ①) with $S_{peak\text{-}max}$ for 10 GHz (in the range ③)

$$\mathbf{S_{peak\text{-}max} = (14{,}3\ f_{[GHz]} + 7{,}1)\ kW/m^2}$$

③ <u>Frequency range 10 ÷ 300 GHz</u>

In this frequency range the values have been established according to the same rule as in the case ①. Finally in this frequency range:

$$\mathbf{S_{peak\text{-}max} = 150\ kW/m^2}$$

In the frequency above 50 GHz, the limit value of power density is only speculative (doted line in Fig.3).

Fig.3. A proposal of safety limits for pulse-power density of EM radiation for workers.

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