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Computational dosimetry on military crew exposed to HF vehicular antenna in near field condition

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Abstract

Within the context of evaluating occupational exposure to Electromagnetic (EM) fields, the military scenario presents interesting and unexplored area of research.
In this study, we examined the near-field exposure of military personnel to a vehicular antenna in a realistic setting. The objective was to enhance our understanding of the induced electric (E-) field and Specific Absorption Rate (SAR) within the human body (Duke, ViP, v.3) when positioned partially outside an armored vehicle. This is a crucial aspect to investigate, especially when the E-field intensities radiated by the antenna may overcome the recommended limits, as in the case herein evaluated. The dosimetric analysis was carried out at different frequencies within the antenna working band (i.e., 35.5 MHz and 85.5 MHz).

1. Introduction

In the frame of the evaluation of occupational exposure to EM fields, the military scenario is still not widely explored, often due to the lack of information regarding the exposure conditions or details about the radiating source [1]. Nevertheless, there is an increasing attention to this topic owed to the extensive use of EM technologies to satisfy diverse operational needs, from broadband jammers to high-rate tactical links and internal communication devices [2], [3]. In this framework, vehicular antennas are typically used. Due to their high transmitted powers in different frequency bands (e.g., HF, VHF, and UHF), such antennas may expose crew personnel to intense EM fields, especially in the near field region where manholes to allow entrance to and exit from the vehicle are located [2], [4]. Given the peculiarity of the exposure scenario, the IEEE Technical Committee 95 (IEEE-TC95) proposed a standard dedicated to the protection of the personnel in a military workplace [5], whereas the International Commission on Non-Ionizing Radiation Protection (ICNIRP), which provides recommendations about the health and environmental protection to non-ionizing radiation exposure, considers the military scenario within the frame of the occupational exposure [6]. In both the two regulatory bodies exposure limits, based on short-term thermal effects are recommended and are: *basic restrictions*, closely related to radiofrequency-induced adverse health effects (i.e., electric field strength and/or the specific absorption rate (SAR) depending on the considered frequency) and *reference levels*, more practical and directly evaluable. If basic restrictions are respected, the reference levels can be surpassed [4]. To ensure this, computational dosimetry is necessary and should reproduce the scenario under investigation [7]. Several numerical studies aiming at assessing such EM exposure are available in literature. However, they are all limited to very simplified scenarios, with generic radiating sources, not specific of the military context [1], absence of human body or human body modeled with homogeneous virtual phantoms [8][9].
To address the need for an accurate exposure evaluation for military crew, more realistic scenarios have been proposed in [10] and [11] where an operator is modeled standing partially outside the manhole of a simplified replica of a military vehicle and exposed to a vehicular antenna working at 16 MHz.
In the present study we considered the same model, with a different radiating antenna working at a higher frequency band. This provides additional information about the exposure conditions of military personnel and how the effects of exposure change with frequency. The virtual model representing the operator is simulated in a realistic posture [10]: leaning towards the edge of the manhole, with one arm bent and laid on the surface of the vehicle, and wearing the personal protective equipment (PPE).

2. Models and Methods

The HF vehicular antenna considered in this study works in the frequency range between 30 MHz and 88 MHz and it was modeled as monopole respecting the requirements of the antenna theory [10], [12] and with dimensions in accordance with the real geometry. Two working frequencies were considered: 35.5 MHz and 85.5 MHz, fed with 50 W of input power. Following the approach presented in [10], [11], the military vehicle was reproduced with a 3D simplified replica.
The dimensions are the same as in [10] and [11], and are here recalled: the base of the vehicle is 835 cm × 280 cm, the middle part is 630 cm × 280 cm and it is tapered and connected to the turret (370 cm × 220 cm), where the

vehicular antenna is mounted. The open manhole has a diameter of 70 cm.

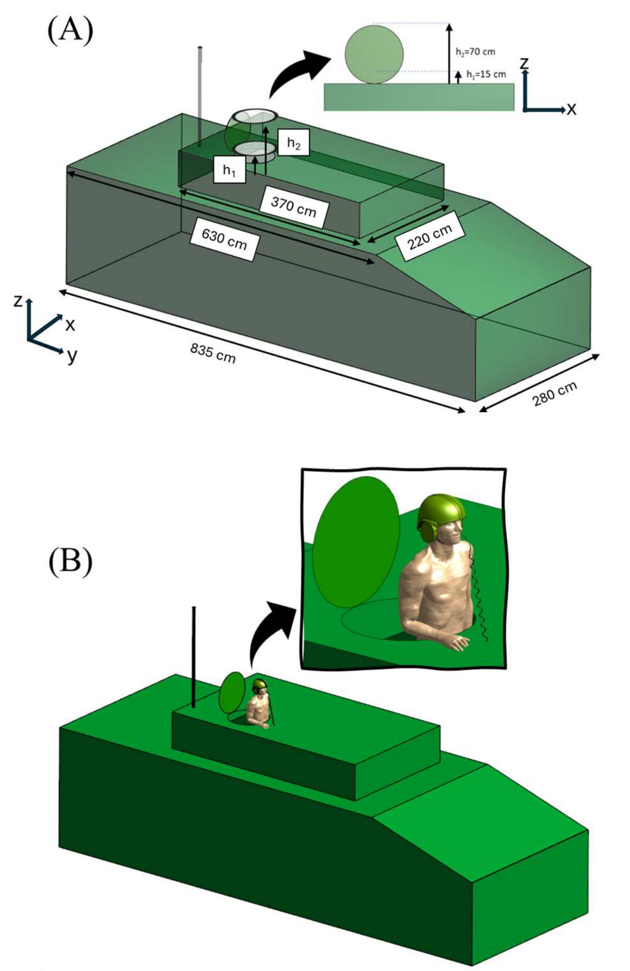

Figure 1. Model of the exposure scenario: (A) Armored vehicle with mounted antenna. Inset shows the two reference distances considered for the analysis. (B) Military operator partially outside the vehicle. Inset show detail of head and trunk with the PPE.

To simulate the presence of the soil, a PEC ground plane was positioned 60 cm under the vehicle to mimic the tires. The model is shown in Fig. 1A.
The standard adult male Duke from the Virtual Population (ViP v.3 [13], i.e., 34-year-old, 1.77 m tall and 70 kg) modeled the operator and was placed through the manhole, with 70 cm of the body (i.e. the trunk) standing outside the vehicle, and leaning towards the edge of the manhole, with one arm bent and laid on the surface of the turret as shown in Fig. 1B. PPE, i.e., helmet and a cabled headset, was included in the model. The helmet consisted of a ballistic shell, a protective foam, and a headset case (Fig. 1B) with the intercom cable, as in [10] and [11]. The antenna and the vehicle were considered PEC material, the dielectric properties assigned to the PPE were the same as in [9] and [10], whereas for Duke they were assigned from the IT'IS Data base[14] at each working frequency. Two radiating conditions were evaluated: (a) in air and (b) with the military operator model exiting from the manhole. In both cases, the antenna was placed over the vehicle. The simulations were carried out within the software Sim4Life (v.7.2, Zurich MedTech AG, Zurich) and the finite difference time domain (FDTD) method [15] was applied to solve the EM problem. Free propagation of the E-field outside the simulation domain was ensured considering the perfectly matched layer (PML) as boundary condition assigned to the lateral and superior walls, while a PEC condition was assigned to the inferior wall to simulate the presence of the reflecting soil. A nonuniform grid was applied to each scenario. The vehicle and the monopole were discretized with a maximum step of 5 cm and 2 mm, respectively, along the three orthogonal directions. When considered, Duke's body, and the helmet were discretized with an isotropic grid of 2 mm. An adaptive subgridding with a maximum step of 0.9 mm in the three orthogonal directions was applied to the cable's wire and Teflon jacket. The overall number of cells in the simulation space was 179.208 MCells, for both cases. Simulations were performed on a Windows11 PC,13th Gen. Intel(R) Core (TM) i9-13900K, 3000 MHz, 24-Core, 128 GB of RAM and 16 GB NVIDIA GeForce RTX 4080 graphic processing units (GPU). Sim4Life GPU computational accelerator "aXware" (Zurich MedTech AG, Zurich), allowed to reduce the computational time. Induced E-field, the whole-body averaged SAR (SARwb), the peak of the SAR averaged over 10 g of tissue in the head (psSARhead) and in the arms (psSARarm) were evaluated as a metric for global exposure and local exposure. Such values were compared with the ICNIRP2020 limits, i.e., 0.4 W/kg averaged over the whole body, and 10 W/kg peak SAR averaged over 10 g of tissue in the head and limbs [6].

3. Results

The simulated antenna, powered with a 50W power supply, was studied at two different operating frequencies: 35.5 MHz, and 85.5 MHz.
Figure 2 shows the distributions of the electric field irradiated in the vehicle space taken on a plane parallel to the base of the vehicle (i.e., XY plane) and located 15 cm above the manhole, which approximately correspond to the height of the waist. The Root Mean Square (RMS) is evaluated, with particular attention to where the operator body might be located (Fig. 2, green circles).
The results at 35.5 MHz show an RMS value of 21 V/m (Fig. 3A, inset). As the frequency increases, the irradiated values also increase, and the field distribution exhibits a less uniform trend. The electric field RMS at 85.5 MHz ranged between 71 V/m and 92 V/m.
Therefore, at 15 cm from the manhole, when the antenna is powered at 85.5 MHz the ICNIRP reference level of 61 V/m is exceeded. At further distances from the manhole plane, where it can be assumed that the head of

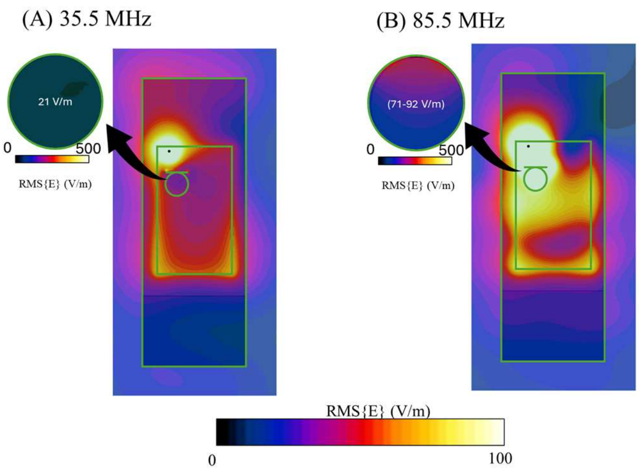

Figure 2. Map of the E-field intensities radiated by the antenna in air (i.e., in absence of the human body): (A)Results at 35.5 MHz, (B) Results at 85.5 MHz. View on the XY plane located 15 cm above the surface of the manhole. In solid green are the contours of the vehicle. Green circles show a zoom of the area where the body waist would be located.

the operator can be located (i.e., about 70 cm), the range of the radiated electric field RMS values again overcomes the ICNIRP reference level (Table 1).

Table 1. E-field values (RMS) radieted locally in the manhole area at 70 cm from vehicle surface.

	35.5 MHz	**85.5 MHz**
E_{min} (V/m)	35	70
E_{max} (V/m)	150	600

Numerical dosimetry in presence of the body of the military operator allowed to investigate whether these values in air would be compliant with the ICNIRP2020 basic restrictions. Fig. 3 shows the distribution of the E-field and local SAR intensities induced inside the Duke model over a coronal section of the body, passing through the center of the head and trunk. In Fig. 3A.1-A.2, the E-field is reported at 35.5 MHz and 85.5 MHz respectively. At 35.5 MHz, results show that the area of the neck is majorly interested by the exposure, with values up to 30 V/m. At 85.5 MHz, E-field hot spots appeared also in correspondence of the limbs. In both cases, an E-field peak also occurred at the level of the ears, induced by the presence of the head-set [9],[10] that caused intensities up to 50 V/m at 35.5 MHz and 80 V/m at 85.5 MHz. Furthermore, the right arm, bent over the vehicle, is always more exposed than the left one, as expected by the shielding effect of the vehicle. The corresponding SAR maps, in the same body section, are shown in Fig. 3B.1-B.2. At 35.5 MHz the values are below 0.25 W/kg everywhere, with the exception made for the area of the ears where it reaches a peak of 0.5 W/kg. Higher values are estimated to be induced at 85.5 MHz with local peaks of 5 W/kg on the right arm and ear. To evaluate the compliance with the ICNIRP limits, the global and local SAR values of whole-body averaged SAR (SAR_{wb}), peak of the SAR averaged over 10 g of tissue in the head ($psSAR_{head}$), in the arms ($psSAR_{arm}$) and in the legs ($psSAR_{leg}$) were computed at both frequencies and are reported in Table 2.

Table 2. Global and local induced SAR values

	ICNIRP (W/kg)	**35.5 MHz (W/kg)**	**85.5 MHz (W/kg)**
SAR_{wb}	***0.4***	0.0037	0.06
$psSAR_{head}$	***10***	0.3	0.99
$psSAR_{arm,right}$	***20***	0.03	2
$psSAR_{arm,left}$		0.007	0.3
$psSAR_{leg,right}$		0.23	0.23
$psSAR_{leg,left}$		0.01	0.22

4. Discussion and conclusions

The aim of this work was to perform a dosimetric study for assessing the safety of military crew exposure in high-power near field conditions within the HF range.
Starting from the work already presented in [9] and [10], a second vehicular antenna, that radiates in the 30 MHz – 88 MHz frequency range, with a maximum power of 50 W, was evaluated. This analysis gives important insights on how the EM interaction with the human body changes with the frequency. Results show that The EM intensities radiated by considered antenna increase with the frequency, until conditions where the E-field intensities overcome ICNIRP reference level (i.e., 61 V/m) are reached, particularly in some areas where the body of the operator could be located. The induced E-field increases, as a consequence. The computational analysis conducted with the body of the military operator, at both frequencies, revealed local hot spots in correspondence of the ears, caused by the presence of the head-set, and of the neck, similarly to what was found in previous studies [9], [10]. Additionally, at 85.5 MHz hot spots appear at level of knees and ankles. At both frequencies, the shielding effect of the vehicle on the body is confirmed by the higher levels induced on the right arm with respect to the left arm.

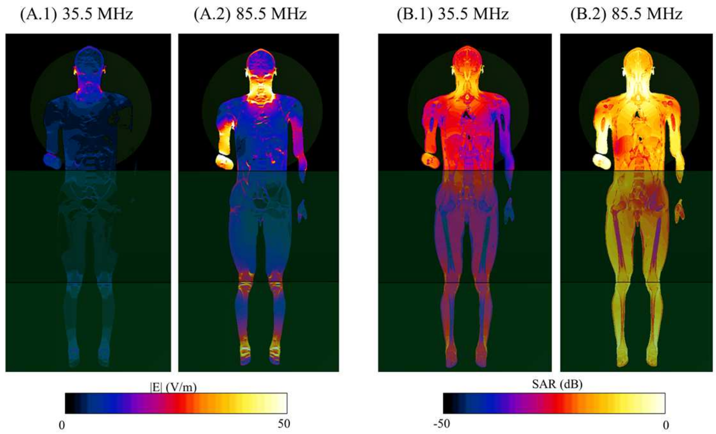

Figure 3. Distribution of the induced E-field (A) and SAR (B) over XZ plane (i.e., coronal plane): comparison between 35.5 MHz and 85.5 MHz.

Nevertheless, local and global SAR show a compliance with guideline limits for occupational exposure, including the peak spatial SAR in the limbs, in all the considered cases. These findings show that in military exposure scenarios, E-field radiated values above the ICNIRP reference level may occur and may depend on the antenna frequency. This does not necessarily cause a non-compliance with the *Basic restrictions.* An accurate numerical dosimetry is an essential tool to assess these aspects.

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