OCCUPATIONAL EXPOSURE ON FM MAST

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Abstract
Large FM transmitters are powerful sources electromagnetic fields. As turning the transmitters off during maintenance and repair is not a viable option for the broadcasting companies and the reference levels are usually exceeded close to the transmitters, a detailed investigation on compliance with basic restrictions is needed before any administrative protection measures are applied (i.e. reduction of the output power, shutting down the transmitter...). To calculate SAR values we prepared a detailed numerical model of 20 kW FM transmitter on a 32 m high mast. An anatomical human model was placed in three different positions inside the mast in the region where the highest values of the electric field were calculated. The electric field strengths in this region were up to 700 V/m. The highest calculated whole body SAR was 0.48 W/kg, whereas the maximum 10 g average SAR in the head and trunk was 1.66 W/kg. The results show that the reference levels in the FM frequency range are very conservative for near field exposures.

Introduction
The approaching last date of the implementation of the directive 2004/40/EC [1] in national legislation of EU countries in April 2012 is approaching. Particularly in some sectors, where high exposures to the electromagnetic fields (EMF) are present, the employers should start to prepare them in advance.
Risk assessment due to the exposure to EMF is at least a two step process. The directive 2004/40/EC and the ICNIRP guidelines [2] defines two types of restrictions: so called reference levels (in the ICNIRP guidelines, in the directive 2004/40/EC they are called action values) and basic restrictions (in the ICNIRP guidelines, in the directive 2004/40/EC they are called exposure limit value).
Reference levels limit the values of the electric and magnetic field strengths and the equivalent plane-wave power density in an unperturbed situation, i.e. no human present; they are easy to use but more conservative. The reference levels are frequency dependent and for electric field strength, they are 61 V/m for FM radio (87 – 108 MHz and VHF TV broadcasting (174 – 223 MHz), whereas for UHF TV broadcasting (470 – 830 MHz) they vary from 65.0 to 86.4 V/m.
Basic restrictions limit the values of the current density at low frequencies and specific absorption rate (SAR) at high frequencies. SAR is the measure of absorbed power per mass of tissue and it is monitored with the intention of preventing excessive tissue heating. To prevent excessive heating of the whole body, the value of SAR is limited for the whole-body to an average value of 0.4 W/kg for occupational exposure. The localized value of SAR intended to prevent excessive heating of a specific highly exposed tissue or organ is allowed to be higher. The value has to be averaged over the mass of 10 g of tissue representing the tissue heat conductivity and heat capacitance. It is limited to 10 W/kg in head and trunk, and 20 W/kg in the limbs.
Radio and TV transmitters are one of the most powerful, high-frequency sources of electromagnetic fields (EMF) and human exposure close to such transmitters can be high and can easily exceed reference levels. However, during maintenance and repair work, the workers have to climb on the transmitters to perform their tasks and turning the transmitters off during maintenance and repair is not a viable option for the broadcasting companies [3, 4].
Data about the values of the electric field strength close to FM transmitters are available in the literature, but the data about the SAR values are limited. European Broadcast Union [3] has estimated the values of electric field

strength and SAR for the workers working on the FM, VHF and UHF towers. It found that for a typical FM transmitter (output power 5 kW), the values of the electric field on the tower are between 25 and 80 V/m. Similar or even higher values of the electric field reaching several hundreds of V/m have been suggested [5, 6]. Remkes [7] presented results of the measurement and calculation of the electric field strength and SAR values on the FM tower. It was found that there is a large safety factor between the value of the reference level and the basic restriction. He also reported that during the maintenance work on the FM tower, the basic restrictions are exceeded when the value of the unperturbed electric field exceeds the reference levels by a factor of more than 40. Due to this high safety factor, it is possible that the workers are still eligible to work close to FM transmitters in many cases; however this must first be proven by demonstrating compliance with basic restrictions.
In this paper the exposure on the FM mast with the 20 kW transmitted power is present. A detailed numerical model of the whole mast with the FM antennas was prepared and the values of the electric field strength and SAR values were calculated for three different positions of the human model inside the mast. The results were compared with the basic restrictions and the exposure of the workers was evaluated.

Materials and methods

We investigated a real broadcasting facility consisting of a VHF and UHV TV transmitter tower and the analyzed FM mast (40 m high). FM antennas are located from the 10th to the 32th m whereas the top 8 m are occupied by additional UHF system. The power on the FM system located on the FM mast (at the connector of the main cable on the combiner) is 25 kW and of the UHF system 5 kW. The assessment of compliance with the basic restrictions was limited to the FM mast only.
For numerical modeling we used the finite-difference time-domain (FDTD) method, as implemented in the SEMCAD (Version 14 – Aletsch) (Speag, Zurich, Switzerland) program package. The simulation was first performed in free-space in order to find the areas with the highest electric fields. Since the area of interest was the inside of the mast structure, the simulation was padded with λ of free space around all the radiating elements. The simulation domain was terminated with a U-PML boundary condition.
We included the whole FM mast (without the top 8 m with the UHF transmitters) in the model. The steel lattice mast is 32.20 m high. The FM transmission system consists of 28 4-dipole antennas.
Antennas are distributed over 8 floors at a 3 m interval. In three horizontal directions, there are 8 antennas whereas in one there are only 4 giving a total of 28. The whole FM transmission system is fed by a 120 m 3 1/8” cable and through 3 step power splitters located on the mast so that the power is distributed to each dipole separately. The attenuation of the whole system of cables and power splitters is 1.1 dB meaning that the 25 kW power on the connector of the main cable to the combiner is reduced to about 20 kW on all 112 dipoles. The system has a circular polarization, with 1/3 of the power feed to the vertical dipoles and 2/3 to the horizontal dipoles. Beside the differences in the power between the vertical and horizontal dipoles, there is also variability of the power between the antennas at different heights. The power on each of the dipole is in the range from 0.37% to 2.2% of the total power. Moreover, the lengths of the cables also vary so there is a phase shift presented between different antennas. By properly defining the power distribution and phase shift between the dipoles, the radiation pattern of the whole antenna system is defined.
The whole main structure of the steel lattice mast was included in the model, as well as all 28 antennas. The power splitters and the cables were not included; instead the excitation of each of the 112 dipoles was individually set to the corresponding power level and phase as determined by the power splitter system and cable lengths. The working frequency was set to 98 MHz.
Once the location of the highest electric field intensity was known, an anatomical human model was inserted into the simulation [8]. The model used was a 34 year old male, 1.74 m tall with a weight of 70 kg. The model was placed at three different heights; at the location of the highest field (middle, height of the standing point 23.7 m above terrain) and 1.3 m above (upper) and below (lower) this point. The lower position is located between the fifth and the sixth floor, where the power fed to the surrounding antennas is the highest. Namely the antennas in the fifth and sixth floor receive 40 % of the total power. The positioning of the human model for the middle position is illustrated in Figure 1.

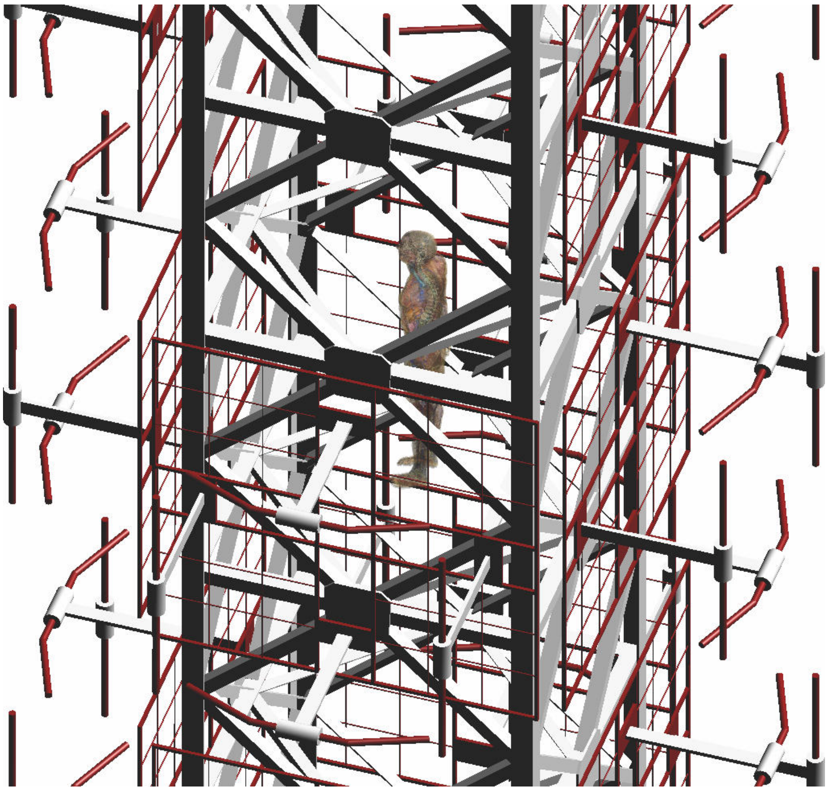

Figure 1: The human model inside the steel lattice mast with antennas in the middle position at the height of 23.7 m.

The simulation with the human model was performed in two steps. In the first step, all the tissue in the human model was set to constant dielectric properties: conductivity was 0.47 S/m and relative permittivity was 44 (2/3 of the relative permittivity of the muscle). The spatial resolution of the model was kept at λ/14 or smaller throughout the whole simulation domain to ensure stability of the FDTD simulation. The incident field was recorded and used in the second simulation via a Huygens box excitation [9]. In the second simulation, only the human model was considered, but this time the spatial discretization was much finer – voxels of 3×3×3 mm were used in the model and tissue was set to inhomogeneous dielectric parameters evaluated from the well-known parametric model [10, 11] for the center frequency used in the simulations (98 MHz). This approach allowed a good resolution of the anatomy and a better precision of SAR computation without causing a gratuitous increase of the computational cost.
To determine the 10 g averaged value of SAR (SAR_{10g}), the efficient averaging algorithm was used based on IEEE C95.3 standard [12], which is included in the SEMCAD package. In comparison to the more general requirement that the tissue over which SAR is averaged only has to be contiguous, the averaging volume in the IEEE standard is more precisely defined – a cube – and thus more widely comparable.

Results

<u>E-field</u>

In general, the electric field strength exceeds the reference levels on the FM mast near the FM and UHF system. The electric field strength on the FM mast could reach up to 700 V/m in the limited volume in the centre of the mast and more than 200 V/m close to the ladder.
The comparison of the measured values of the electric field strength with the calculated is shown in Figure 2 the results for the electric field in and around the mast without the presence of the human model is shown for two locations – the first one is in the centre of the mast and the second one is close to the ladder inside the mast presenting typical exposure during climbing on the mast.

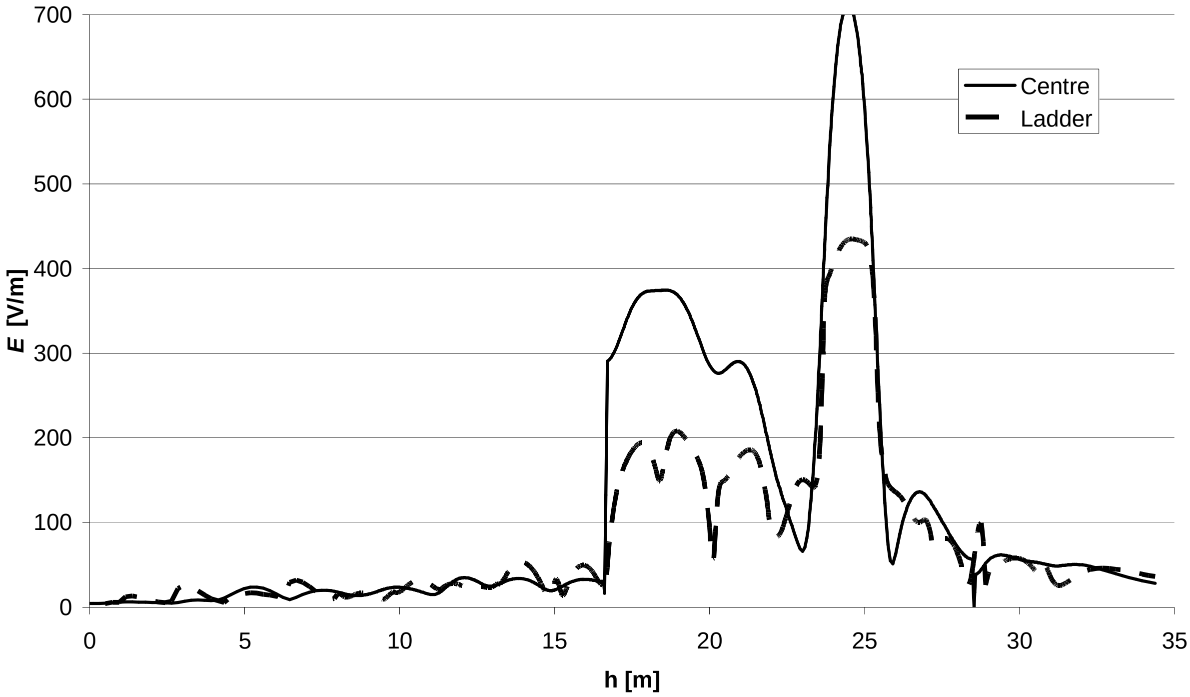

Figure 2: Comparison of the electric field inside the FM mast over the height. The E field's strength (V/m) values are shown for the centre of the mast (centre) and close to the ladder (ladder). The human body was not included – free space situation.

The values of the electric field strength are lower close to the ladder, since the distance to the good conducting structures such as the ladder and the steel lattice mast is smaller compared to the centre of the mast and the electric field distribution is affected greatly. Besides the parts of the mast structure, also the human body affects the electric field distribution as can be seen in Figure 3.

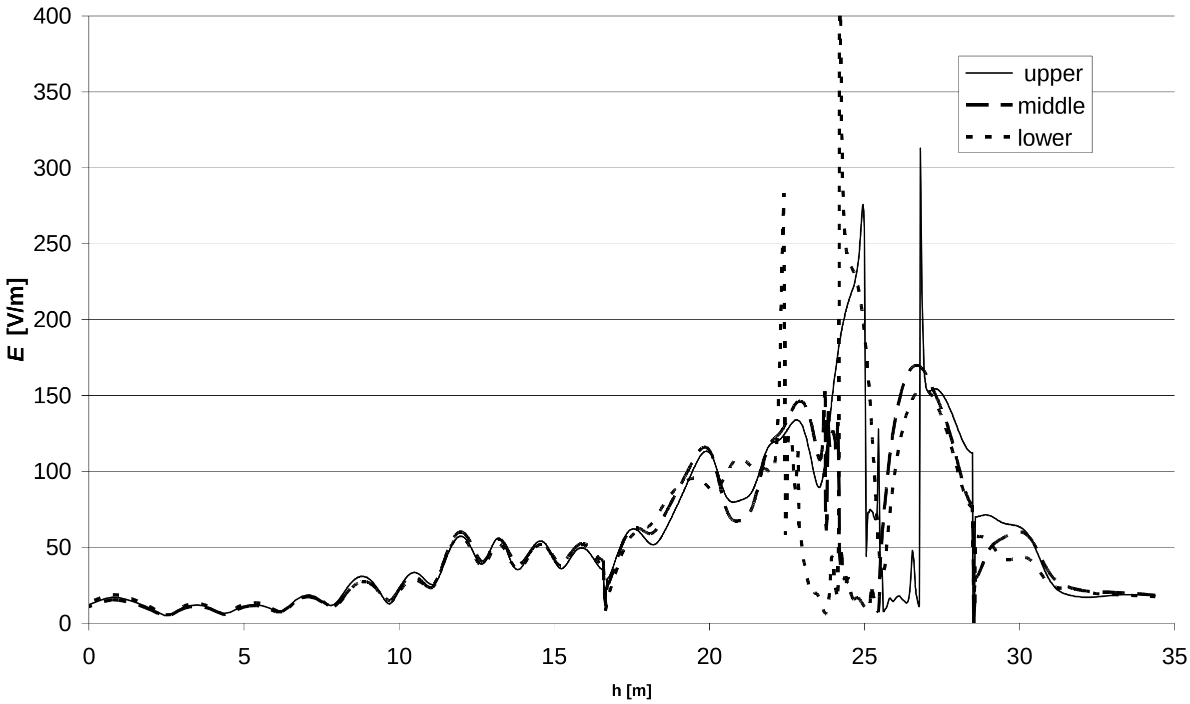

Figure 3: Comparison of the electric field inside the FM mast over the height. The values of the electric field are shown for three different positions of the human model at the height of 22.4, 23.7 and 25.0 m.

Not only is the electric field greatly reduced inside the human model and close to it, but the human body also exerts influence over the electric field distribution in other locations inside the FM mast. The effect of the human body on the electric field distribution is presented also in Figure 4, where vertical cross sections through the centre of the mast are shown for free space and lower, middle and upper positioning of the human body inside the mast.

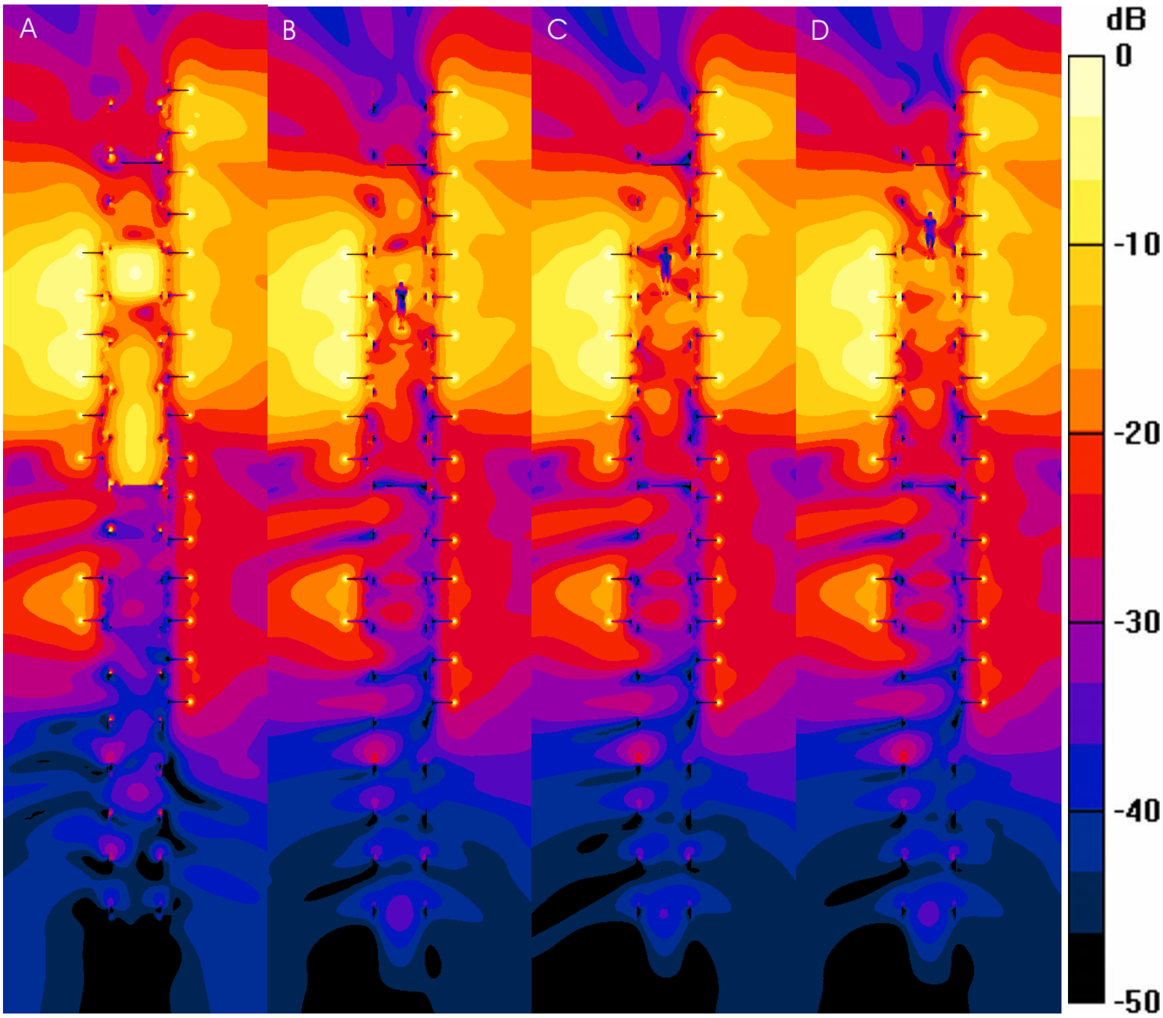

Figure 4: Electric field in the vertical cross section of the FM mast. A: free space (without the human model), B: lower position (h = 22.4 m), C: middle position (h = 23.7 m), D: upper position (h = 25 m) of the human model inside the FM mast. The values are normalized to 1 kV/m and shown in logarithmic scale.

SAR

As the values of the electric field exceed the reference levels, SAR values in the human model were calculated. The results are presented in Table 1, where the values of the average whole body SAR_{wb}, the maximum 10 g averaged SAR_{10g} for the head and trunk and for the limbs are given separately.

Table 1: SAR values calculated in the model for the lower position (height 22.4 m), middle position (height 23.7 m) and upper position (height 25 m) of the human model inside the FM mast.

position of the model	**SAR_{wb} [W/kg]**	**head and trunk max SAR_{10g} [W/kg]**	**limbs max SAR_{10g} [W/kg]**
lower	*0.48*	*1.66*	*8.02*
middle	*0.17*	*1.03*	*1.99*
upper	*0.15*	*1.05*	*1.96*

From the results of SAR values, it can be seen that the whole body SAR_{wb} is below the basic restrictions (0.4 W/kg) in the middle and upper position of the human model inside the FM mast, but it is slightly exceeding it in the lower position, where the power on the antennas is at its highest. The maximum value of the 10 g averaged SAR_{10g} is always below the basic restrictions (10 W/kg for the head and trunk, 20 W/kg for the limbs). Nevertheless, still below the basic restriction, the maximum value of the 10 g averaged SAR_{10g} in the limbs is high in the case of the lower position of the human model.

Discussion and conclusions

The electric field strengths on the locations accessible to the maintenance and repair workers inside 20 kW FM transmitter were determined by numerical calculations. Since the electric fields in the FM mast exceed the reference levels by a factor of up to 10, we also numerically calculated SAR values for three different positions of the human body inside the FM mast. If we calculate the safety factor *S* as in [7]

$$S = \left(\frac{E_{calculated}}{E_{reference\ level}} \right)^2 \frac{SAR_{basic\ restriction}}{SAR_{calculated}}$$

for all three positions using the highest value of the electric field in the region where the human model is positioned, we obtain following values of the S: for lower position, it is ≈100, for middle position, it is ≈320 and for upper position, it is ≈250.

In [7] the safety factor is 42. The values we obtained are higher; however the difference is not so unexpected since there are some differences between the models: different albeit similar transmission mast, different anatomical human models, different numerical method, discretization and resolution. Nevertheless, it is evident that for near field exposure close to FM transmitters, the reference levels are conservative. Based on SAR calculations it is sometime possible to demonstrate, that it is safe to work on the mast without lowering the output power or even turning it off.

References

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