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Occupational Exposure to Base Stations—Compliance With EU Directive 2004/40/EC

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The rapid growth of mobile communications has not only led to a rising number of mobile telephones. It has also made base stations essential for services widespread on many roofs. However, not everyone is aware that working close to sources of high frequency electromagnetic fields (EMF), such as transmitter antennas for mobile phones, pagers and police, fire and other emergency services, can result in high EMF exposure. This paper deals with measurements and calculations of the compliance boundary for workers in one typical roof top base station setting according to EU Directive and other relevant EN standards.

mobile communications   exposure assessment   compliance testing

1. INTRODUCTION

Directive 2004/40/EC [1] introduces the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents including electromagnetic fields (EMF). One of the most important tasks is to identify its major impact on industry and on the improvement of workers' safety. This directive introduces binding exposure limit values (ELVs) but also action values, i.e., values under the ELVs, but above which employers are obliged to implement measures specified in the directive. The action values of the frequency spectrum of the mobile base stations are presented in Table 1.

TABLE 1. Values According to EU Directive [1]

System	E-field (V/m)	Power Flux Density (W/m^2)
GSM 900	$3\sqrt{950} = 92.5$	950/40 = 23.7
GSM 1800	$3\sqrt{1800} = 127$	1800/40 = 45
UMTS	$3\sqrt{2170} = 139.7$	2170/40 = 54.2

According to the results of a survey on occupational EMF exposure there have been cases of excessive radiofrequency (RF) occupational exposure from various devices. Situations that include personnel routinely performing maintenance work on roof top mounted base stations could involve overexposure [2]. Levels of occupational exposure vary considerably, and are strongly dependent upon output power, distance, number of active transmitters, direction of the antenna and the complexity of the cell configuration. In many cases, occupational exposure occurs in the near field of a source, and exposure assessment requires a detailed investigation.

Generally, the level of exposure to mobile communications transmitters depends on the type and direction of the antenna: dipole antennas, such as those used for pager services, can produce much higher field strengths in their direct vicinity than

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sector antennas for a mobile phone service, which usually operates with a much lower transmitter power. At distances greater than 4.5–6 m, the exposure levels are in compliance with the EU directive for workers [1]. However, as the distance to the antenna is reduced below this, exposure values rise quickly. The basic rule of thumb states that exposure is four times higher when you halve your distance to the antenna [3]. This means that if you are only a quarter of the recommended safe distance away, the degree of exposure is 16 times higher. At one tenth of the distance, exposure is even 100 times greater.

2. METHODS

This investigation was carried out on a typical roof top (Figure 1) where maintenance workers and other individuals have access to the base station (Table 2). The investigation consisted of calculations and spot measurements of the rms value of the electric field strength in about 50 measurement points located around the GSM 900, GSM 1800 and UMTS base station antennas—particularly at the position of maximum field.

In our case, RF exposure was assessed in the radiating near-field regions where free-space propagation could not be assumed. This required independent measurements of both electric (E) and magnetic fields (H) and afterwards taking into account the highest. Due to the range of radio frequencies (GSM 900, GSM 1800, UMTS) currently available literature points out that it is usually sufficient to measure only the electric field (E) since magnetic fields (H) are only measured up to 300 MHz. A ground plan of the domain of the investigation with precisely measured *E*-field values at each point of investigation is presented in Figure 2.

Results of measurements show a non-compliance area only in the main lobe and in the immediate vicinity of the antennas at peak traffic. The described measurement methods are unsuitable for defining compliance boundaries (*CB*) for the antennas of each individual system; therefore, some formulas that allow the calculation of actual exposure are established according to the literature [4]. In fact, application of the calculation procedures is simpler and faster than measurements, giving results with a precision comparable to measurement uncertainty. According to Faraone [4] and

Figure 1. Roof top location of the investigated base station.

TABLE 2. Detailed Description of the Base Station Mounted of the Roof Top at the Investigated Location

System	Sector (°)	Power	Configuration	Frequency (MHz)	Antenna
GSM 900	0, 150, 270	8 (W/ch/sector)	6/6/6	947.5–959.9	K 739 624 X
GSM 1800	250, 320	8 (W/ch/sector)	4/4	1835–1850	K 737 974 X
UMTS	0,150, 270	20 (W/ch/sector)	1/1/1	2155–2170	K 742 213 X

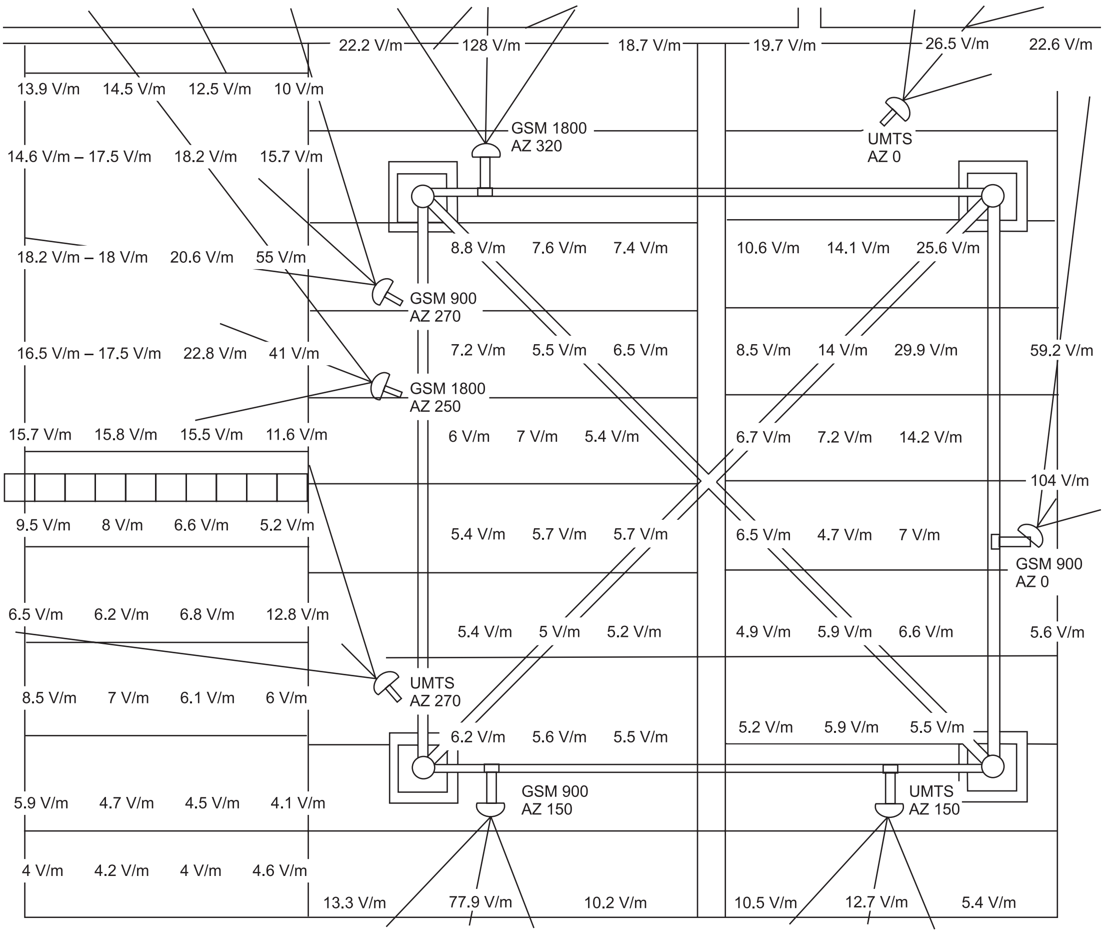

Figure 2. Ground plan of the domain of the investigation with precisely measured *E*-field values at each point of investigation.

Cicchetti [5] *CB* could be calculated with the following formula:

$$CB = \rho_0 \sqrt{\frac{\sqrt{1 + \left(\dfrac{P \cdot 2^{-\left(\phi / \bar{\phi}\right)^2}}{S_\mathrm{m} L \rho_0 \bar{\phi}} \right)^2} - 1}{2}} \qquad (1)$$

$$\rho_0 = \frac{\bar{\phi}}{2\pi} LG \quad (\mathrm{m}),$$

where *CB*—compliance boundary that defines a volume outside which any point of investigation is deemed to be compliant, S_m—limit value according to the EU Directive [1], *L*—maximal dimension of the sector antenna, *P*—total radiated power, *G*—gain of the antenna, $\sqrt{\bar{\phi}}$—horizontal half power beamwidth (rad).

Exposure ratio (*ER*) represents the assessed exposure parameter for a source, expressed as a fraction of the related limit at a specific frequency. For field parameters, *ER* is defined by

$$ER = \mathrm{MAX}\left[\left| \left(\frac{E}{EL} \right)^2, \left(\frac{H}{HL} \right)^2 \right|_{f=100\ \mathrm{kHz}}^{f=10\ \mathrm{GHz}}, \left| \left(\frac{S}{SL} \right) \right|_{f=10\ \mathrm{GHz}}^{f=40\ \mathrm{GHz}} \right]; \qquad (2)$$

where *ER*—exposure ratio at frequency *f* for the source, *EL*—investigated E-field limit at frequency *f*, *HL*—investigated H-field limit at frequency *f*, *SL*—power flux density limit at frequency *f*, *E* is the assessed E-field at frequency *f* for the source, *H* is the assessed H-field at frequency *f* for the source, *S*—assessed power flux density at frequency *f* for the source, *f*—frequency of the source.

ER of an individual base station at different distances is presented in Table 3.

TABLE 3. Exposure Ratio (*ER*) of an Individual System at Different Distances (ρ)

	Exposure Ratio (*ER*)		
ρ (m)	GSM 900	GSM 1800	UMTS
0.15	4.79	3.16	1.19
0.35	2.05	1.35	0.51
0.55	1.30	0.86	0.32
0.75	0.96	0.63	0.24
0.95	0.75	0.50	0.19
1.15	0.62	0.41	0.16
1.35	0.53	0.35	0.13
1.55	0.46	0.30	0.11
1.75	0.41	0.26	0.10
1.95	0.37	0.24	0.09
2.05	0.35	0.22	0.09
2.15	0.33	0.21	0.08
2.25	0.32	0.20	0.08
2.35	0.30	0.19	0.08
2.45	0.29	0.18	0.07
2.55	0.28	0.18	0.07
2.65	0.27	0.17	0.07
2.75	0.26	0.16	0.06
2.85	0.25	0.16	0.06
2.95	0.24	0.15	0.06
3.05	0.23	0.14	0.06

The formulas make it possible to calculate the average power density and the required *CB*. Furthermore, they are validated by measurements at peak traffic in the main lobe of a GSM 900 antenna. These formulas are convenient for exposure assessment if maximal radiated power is admitted. Calculations represent quite a simple way to determine total power density also if there are more radio sources nearby.

2.1. Measurement Results

The measurements were made with a radiation meter EMR-300 (Wandel&Goltermann, Germany) with an isotropic electric field probe type 8 (100 kHz–3 GHz) (Narda STS, Germany), a portable personal computer and a wooden tripod [6].

Considering non-homogeneous field strength, linear spatial averaging according to Standards prEN 50400:2004 [7] and prEN 50401:2004 [8] was applied. To assess exposure either a scanning procedure was used whereby the engineer moved a hand-held antenna slowly within the area of interest, or an isotropic field probe fixed on a wooden tripod measuring the rates at different heights in the area of interest could be applied. The measurements were focused on the maximum *E*-field strength values averaged over a 6-min interval and the location of the three assessments for each point of investigation (heights of 1.1, 1.5 and 1.7 m). Points were selected on worker accessible areas with 1.5-m grid resolution.

Before entering the domain of investigation where workers may have access when the base station is put into service, action values for each applied frequency of the mobile communication spectrum according to the EU Directive must be determined. Since the measurements were obtained by a broadband *E*-field probe in the range of 100 kHz–3 GHz, the most rigorous action value E_R = 92.5 V/m according to the applied frequencies for the test compliance was taken into account.

The results of the investigation show that action values were exceeded close (up to 1.5 m) to the GSM 900 (azimuth 0^o) and GSM 1800 (azimuth 320^o) antennas respectively. Based on the spatial averaged *E*-field values, total *ER* was exceeded but within the expanded uncertainty of the measuring system. Despite the relative large number of points of investigation we could not identify the exact area where action values were exceeded. Thus, more points of investigation would be needed to define *CB* in great detail. Since this approach is very time consuming and costly we focused on calculations that could provide information on *CB*.

2.2. Results of Calculations

The equation derived in section 2 was used to calculate the course of *ER* (the assessed exposure parameter for a source, expressed as a fraction of the related limit) for each system. Catalogue data on antennas and operator's data were used and the highest possible value was taken for the transmission power.

The easiest way to determine the areas around the base station antenna was to use the calculation path by means of Equation 1. Thus we calculated *CB* for each system with adequate power flux

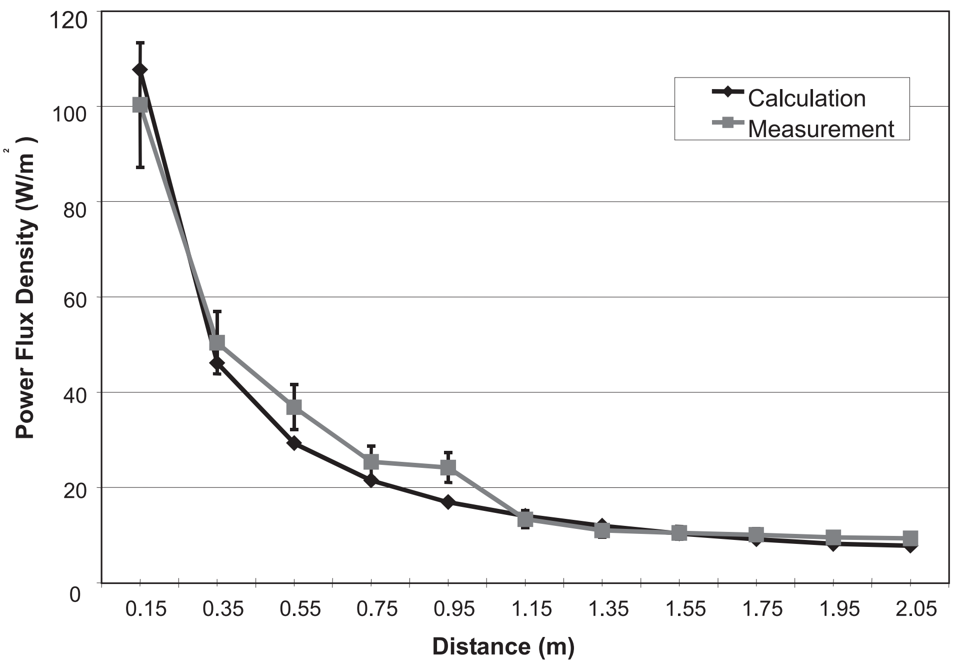

Figure 3. Comparison of measured and calculated power flux densities.

densities. *CB* was determined by the action value of power flux density (Table 4). The scatter domain (*SD*) was respected up to 10% and the relevant domain (*RD*) up to 5% of the power flux density action value.

TABLE 4. Calculation of Compliance Boundary (*CB*), Scatter Domain (*SD*) and Relevant Domain (*RD*) for Each System as a Function of Maximum Radiated Power

System	*CB* (m)	*SD* (m)	*RD* (m)
GSM 900	0.72	6.57	11.41
GSM 1800	0.47	4.15	1.78
UMTS	0.18	1.78	3.49

When determining the areas around individual antennas (*CB*, *SD*, *RD*) only the radiation of each antenna was taken into account, which was not a guarantee that outside the *CB* area, total *ER* (*TER*; the maximum value of the sum of *ER*s of all relevant sources) would be lower than 1. Thus, the contributions for each individual system as a function of a distance and side lobes were calculated. Afterwards individual contributions (*ER*) were added with respect to mutual spatial arrangement of antennas, and *TER* was obtained. Based on *TER* calculations, we determined how much the safety distance of the said antenna was to be increased.

In the case of the GSM 900 (azimuth 270^{o}) antenna, the diameter of *CB* had to be increased from 72 to 82 cm. The GSM 1800 (azimuth 250^{o}) antenna, on the boundary of the *CB* of the GSM 900 antenna contributed only 0.08 to *ER*. The *CB* of the UMTS (azimuth 0^{o}) system had to be increased from 18 to 21 cm due to the contribution (*ER* = 0.05) of the GSM 900 (azimuth 0^{o}) system.

2.3. Comparison With the Measurements

In addition, the power flux density measurements for the GSM 900 antenna operating at full power were compared with the calculations obtained from Equation 1. Flux density was measured in the main beam of the antenna with the starting point being 15 cm from the back of the antenna and with spacing intervals of 10 cm up to the total distance of 2.05 m.

Based on the compared calculated and measured values of power flux density for the GSM 900 system we could conclude (Figure 3) that the use of simple predicted equations was adequate, if the highest possible power was used as the data of transmission power. A comparison of the results shows good agreement between calculated and measured results when a worst case scenario is assumed.

3. DISCUSSION

Workers' exposure to EMF within the area of base station antennas was analysed by measurements and by means of simple predicted equations used for calculating average power flux density.

Measurements with a wide-band probe only provided a rough image of the situation in the domain of investigation, because it was still not possible to determine the numerically defined areas despite a selection of a larger number of points of investigation. The circumstances made us use simple equations for calculating average power flux density. The validity of the equations was first checked with detailed measurements at the point of maximal radiated power of a specific antenna and then generalised to antennas of all systems. Equation parameters were selected for the worst possible case and, thus, *CB* around the antennas was determined. Since there were several antennas of various systems in the neighbourhood, radiation contributions of all systems had been taken into account when determining safety distance.

*CB*s of various systems differ from one another, yet it seemed most reasonable to consider the greatest safety distance when entering the area [9]. From the situation described in this paper we could conclude that staying in the main beam of the antennas at a distance up to 1 m could exceed the action values of field intensity stipulated by the EU Directive [1].

Based on the legal provisions of the Directive and on the presented case we can conclude that the boundary value of field intensity of the presented frequencies is set at a high level for professional exposure. *CB*s are limited to a small space close to radiation antennas. The situation deteriorates when there are several various radio source operators on the same roof.

When taking basic restrictions (Specific Absorption Rate [*SAR*]) in the bodies of the exposed personnel into account, *CB* is expected to be even shorter than for action values.

Protective measures for the owners and administrators of affected buildings take on an even greater importance. The dangers posed to people who access these roofs or areas close to antennas, whether with or without permission, must be minimised. It is easy to prevent access to antenna installations on towers. However, it is considerably more difficult to restrict access to installations on the roofs of buildings as a number of personnel require regular access to roof areas, e.g., house technicians, administrators, servicing personnel for air-conditioning systems and elevators, roofers, chimney sweeps, decorators and cleaners. For most of these people, the topic of EMFs is completely new and they have either no or very little understanding of the subject.

Roofs with several transmitter antennas are particularly important as the levels of threshold values may not simply vary; they may also be exceeded more quickly. The risk of exceeding threshold values is exceptionally high in these areas. The solution lies in training, good equipment and modern measurement technology. Thanks to these latest developments people with very little experience can make quick and easy measurements to protect themselves effectively—even in complex environments such as roofs with a variety of different services (mobile phone or pager antennas, VHF, radio or TV). These measurement techniques take account of the different threshold values for EMF, which vary according to the frequency and the absorption characteristics of the human body. The user therefore receives a reliable result—as a percentage of specific standards—that requires no interpretation, and does not have to know the frequencies and their corresponding field strength threshold values.

It should be also pointed out that some roof-makers and workers involved in similar work may not be categorised as occupationally exposed to RF fields, and that *CB* should be determined according to Council Recommendation [9].

A few simple procedures allow building owners and administrators to guarantee safety in the EMF created on their roof or property. The following sections offer practical suggestions for protecting people against the dangers posed by EMF. They make the complex subject of EMF simpler to understand and suggest appropriate safety measures to be implemented. The most important elements of these measures are as follows.

3.1. Training

The aim of appropriate training is to inform affected personnel about the sources and dangers of EMFs as well as about correct protective measures and behaviours. These training measures should be repeated regularly and participation should be documented. In addition, training should include instruction on the correct methods of using measurement technology. This prevents mistakes which could lead to inaccurate results and therefore put personnel in direct danger.

3.2. Equipment for Personnel Protection

While working in close proximity to electromagnetic radiation, normal protective clothing for the specific situation (protective boots, helmet, gloves, etc.) must be supplemented with a field monitor worn on the body or, in extreme cases, a conductive suit. Field monitors are easy to use and can evaluate field strengths according to corresponding legal threshold values. If a person enters an area where field strengths are close to or in excess of the threshold value, the user is alerted by optical and acoustic or vibrating warning signals.

3.3. Determining and Evaluating Possible Danger Areas

As well as determining exposure areas using measurements and simulations, EMFs should also be calculated and compared with the legally required or recommended threshold values.

3.4. Marking and Controlling Danger Areas

Once a potential *CB* has been identified with appropriate measurements or calculations, danger areas must be clearly marked. This must be done with notices with the appropriate symbols and, if necessary, with physical barriers.

3.5. Documentation

It is essential to document results correctly so they can be tested by independent authorities and compared with subsequent measurements, e.g., after an additional transmitter has been installed or when a particular deadline has expired.

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