

ELECTROMAGNETIC FIELD PATTERN IN THE ENVIRONMENT OF GSM BASE STATIONS*

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Abstract. Three mobile phone systems are used in Poland: analog, operated at the 450 MHz frequency range, and two digital systems operated at 900 MHz and 1800 MHz. The GSM – Global System for Mobile Communication meets all relevant requirements, and it is most widely used throughout the world. According to the mobile phone concept, the whole communication area is divided into sub-areas (cells) where base stations are located. The base stations are provided with the transmitter units mounted on free-standing masts, high chimneys and building roofs, including those of the residential buildings. The transmitter antennas of the base stations constitute a source of 935–960 EMF radiation. This work analyses the essential characteristics of the base station antennas from the point of view of radiation intensity. The analysis is based on the results of EMF measurements performed by experts of two relevant research institutes. For inaccessible antennas, the measurements were performed at the accredited laboratory.

REGULATIONS ON THE PROTECTION AGAINST ELECTROMAGNETIC FIELDS IN POLAND

Electromagnetic fields (EMF) within the area of the so-called far field are referred to as electromagnetic radiation, which propagates around the source in the form of electromagnetic waves. Such waves carry energy (which then if modulated by a suitable electric signal becomes a carrier of information). The energy transported by electromagnetic wave for the GSM network at the frequency of 900 MHz belongs to the interval of non-ionising radiation. This is because one energy quantum of this energy is too small to ionise matter that can break an atom or a particle into ions.

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The GSM network belongs to microwave frequency range comprising, according to Polish regulations, frequencies from 300 MHz to 300,000 MHz. Omni and directional TxRx (transcieiving) antennas and mini-link antennas generate EMF.

There are independent legal acts on the protection of workers dealing with the equipment generating EMF (regulations on safety at work) and on the protection of people and natural environment in the form of relevant regulations, decrees and orders (1–3).

There are two main aims for the protection against EMF of non-ionising radiation range:

- to limit or eliminate the occurrence of EMF radiation in the places where people are present;
- to limit the time of people's presence in the places where stronger EMF might occur.

The regulations on the human and environmental protection take into account permanent presence within the EMF including children, pregnant women, elderly people, the disabled, and sick people. The protection of people within a larger EMF is regulated by the appropriate Regulation (1). It stipulates the admissible level of the non-ionising radiation in the proximity of the equipment generating EMF. For the radiation frequency range above 300 MHz to 300,000 MHz, the admissible value of mean power density is 0.1 W/m^2 . Measurements of the admissible levels of non-ionising electromagnetic radiation are not performed at places which are inaccessible to people. EMF exposure of the workers operating and servicing the equipment of the cellular network is controlled by relevant regulations on health and safety at work when using the equipment generating EMF of microwave range (3). There are three protection zones: intermediary, imminent and dangerous according to the regulations, specifying also the conditions for being present within them. The limits for the above mentioned values are presented in Table 1.

Table 1. Limits for the protection zones for the frequency range of 300–300,000 MHz for stationary fields

Zone	Power density (W/m^2)	Rules for people's presence	Comments
Hazardous	> 100	Presence without protective clothing forbidden	
Dangerous	20–100	Limited time depending on power density	Occupational exposure
Intermediate	0.1–2.0	Work shift	
Admissible radiation level	> 0.1	Presence of strangers forbidden	Environmental protection

THE CHARACTERISTIC OF TECHNICAL SOLUTIONS FOR GSM RADIO BASE STATION ANTENNAS POSITIONING

In mobile telephony systems the whole area covered by a given network is subdivided into smaller areas (called cells) represented as hexagons with BASE TRANSCIEIVER STATIONS (BTSs) in the middle. The mobile station communicates with the BASE STATION at 890–915 MHz and the BASE STATION communicates with the mobile station at 935–960 MHz. Cells may be from a few

hundred metres in diameter in office centres, up to ten to twenty kilometres in the areas of low population density.

BASE STATIONS are the most plentiful of all elements in infrastructure of every cellular network. It is the population density that determines the number of BASE STATIONS in a given area. In Poland, in large cities up to 30 BASE STATIONS are planned to be installed by the operator of a given GSM network.

There are different configurations of BASE STATIONS depending on their location (city, suburb, rural or road). In the city and its suburbs three sector antennas are most frequently used; directional antennas with 1 or 2 sectors as well as omni antennas characteristic of rural and road areas. There may be up to three sectors for each BASE STATION and different antenna configurations for one sector depending on the operator:

2 TxRx antennas for each sector, each of which works with one transmitter, maximum output power without losses is 22.4 W; or

1 TxRx antenna and 1 Rx antenna for each sector, working with two transmitters, maximum output power without losses is 10 W.

In cities, BASE STATION antennas are installed mainly on buildings, in suburbs on church towers or chimneys of heat and power generating plants. In the rural areas and along the roads there are antennas on masts (steel towers).

With regard to the environmental protection, installations on the buildings (including residential buildings, and hospitals) are most important. There may be antennas installed on the building of steel construction placed on the rooftops, penthouses, in the corners of the roofs and on gable walls.

There are also mini-links (microwave radios) for the so-called direct radio transmission installed on the BASE STATIONS. You can also talk about TRANSMISSION BASE STATIONS with many mini-link antennas installed, however, other BASE STATIONS are also used to mount a few mini-links depending on the site location.

Transmitting and operating equipment of BASE STATION is positioned either indoors (INDOOR BTS, MINI INDOOR BTS), outdoors (OUTDOOR BTS) or on the rooftops (ROOFTOP BTS). In buildings there would be a special room prepared for the equipment as close to the transmitting antennas as possible (on the top storeys). Outdoor, BASE STATION equipment is put in original, shielded cabinets inside the containers close to towers, high chimneys and platforms. Radio signals are transferred from the above mentioned equipment to the transmitting antennas of the BASE STATION via feeders. BTS equipment is installed in a similar way on the rooftops. Installation techniques of the BASE STATION antennas are shown in Fig.1.

In cities, antennas are placed 30–40 m above the ground level, and in suburbs and rural areas 60 m above the ground level. Natural ground elevations are very often chosen for tower locations.

If antennas are placed on buildings, it is the antenna height from the roof level that matters. In practice, antennas are put 3 to 6 m above the roof level. On each mast, there are at most two TxRx antennas working in two different sectors, and their directions are 120 deg. apart. Two TxRx antennas working in the same sector require a minimum distance of 5 m between antenna brackets. Antennas have been recently installed at separate corners of the roof for each sector so that they could be considerably separated. Mini-link antennas are mounted on the same

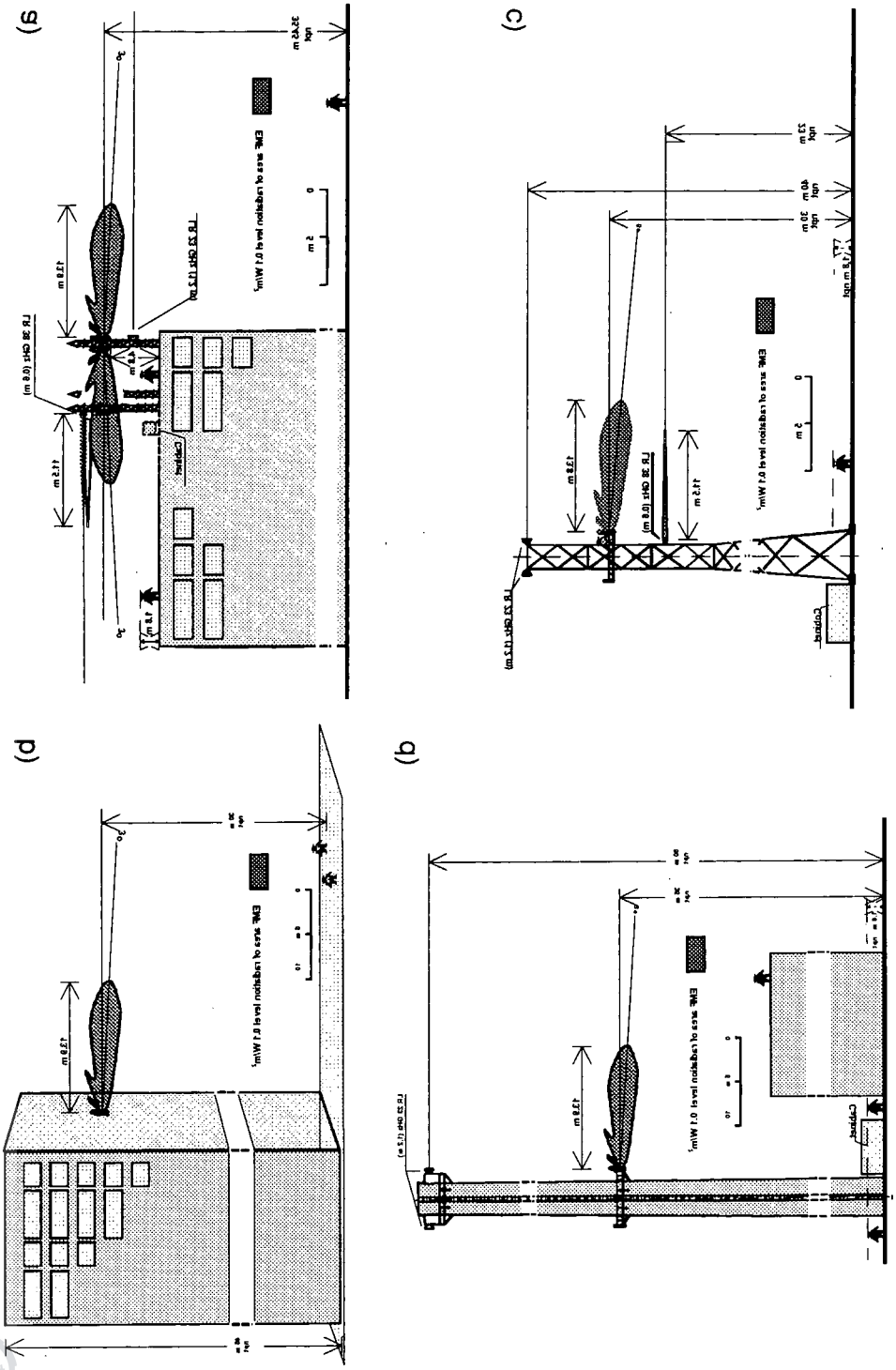


Fig. 1. Ways for mounting GSM antennas together with their vertical characteristics: (a) rooftop; (b) building facade (c) tower; (d) chimney of heat and power generating plant.

masts as RBS antennas with at least 1 m distance between bottom of the RBS antenna and the top of the mini-link. There are mini-link antennas installed either together with the radio module (so-called integrated antenna) or separately.

THE CHARACTERISTIC OF RBS ANTENNAS

There are three major types of antennas installed in GSM networks in Poland:

- 1) Omni (2 types) about 3,000 mm high, gain 10.5–11 dBi, vertical power beam width of 7 deg;
- 2) Directional (about 15 types), one antenna with vertical polarisation, from 987 to 2,700 mm high, gain 13.5–18.5 dBi, horizontal power beam width of 65 deg. and 90 deg., vertical power beam width of 6.5, 8.5, 9, 13, 17 deg. and
- 3) Expolarised directional antennas (about 5 types), 2 antennas with independent polarisation in one panel from 964 to 2,500 mm high vertical power beam width of 8–21 deg.

Among directional antennas there are some types that possess the so-called adjustable tilt for 3–15 deg. and the ones for which the tilt is fixed at 5–12 deg. In practice, mechanical tilt is used for 3–9 deg.

The power of the transmitter working with one RBS antenna is 20 W per antenna without losses. There may be losses on control units, matching units, couplers and coaxial cables or wave-guides. Depending on the distance between antenna and RBS, radio signal is transmitted via feeders of various length and losses. Up to 50 m, 7/8" feeders (attenuation 4.2 dB/100 m) are used (4). There are also the so-called combiners in RBSs. The losses of the radio signal on the combiner are estimated to approximate 3 dB. This is why the antenna input power may be half of the transmitter output power. As for the environmental protection, it is also antenna tilt that runs the higher risk of exceeding the admissible level of the non-ionising electromagnetic radiation in the areas accessible to people.

There are vertical radiation patterns of Tx antenna for electric tilt of 3 and 15 deg. (Fig. 2). Assuming that the antenna main lobe is above the rooftop of the

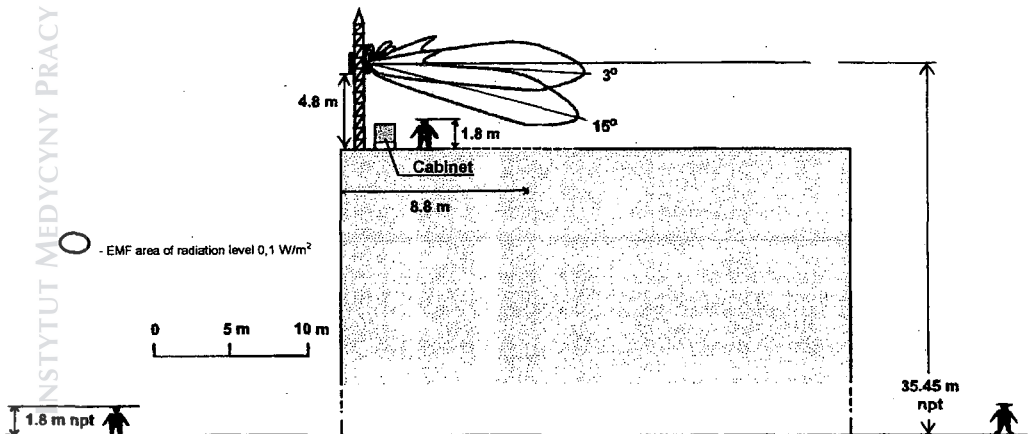


Fig. 2. Vertical radiation pattern of Tx antenna of GSM BASE STATION, depending on the antenna electric tilt.

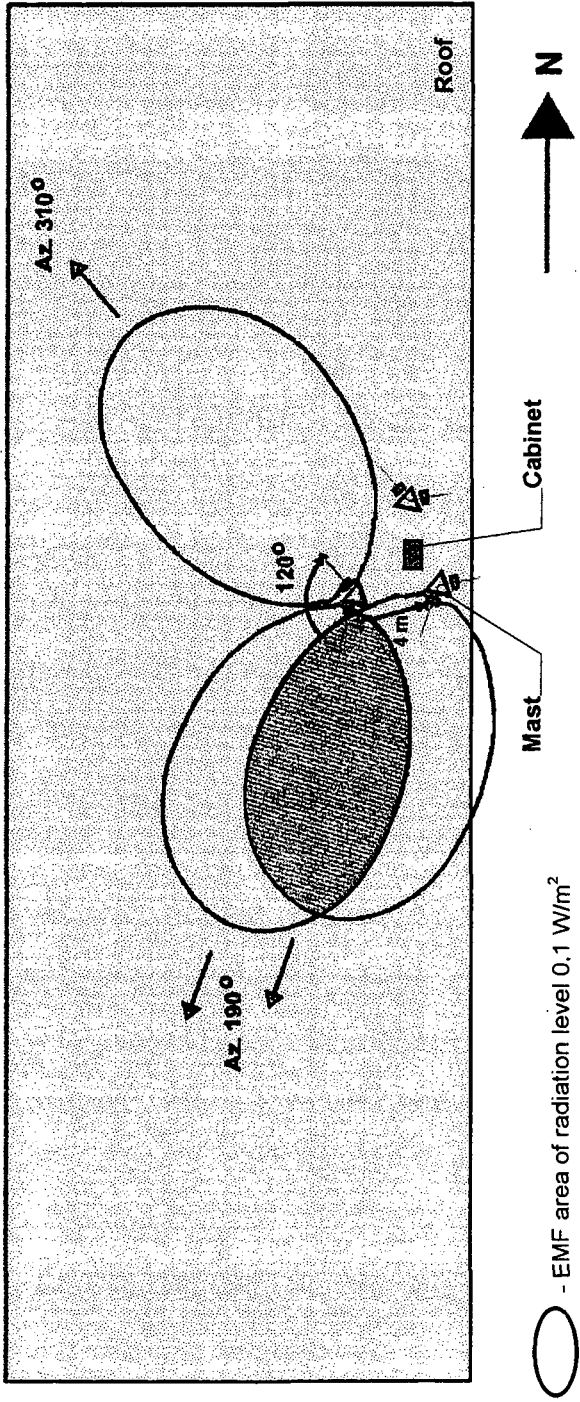


Fig. 3. Horizontal polarisation of GSM BASE STATION antennas on the rooftop.

building, the admissible EMF level for people shall be exceeded at 8.8 m from the bottom of the mast only for 15 deg. tilt. If antenna is lowered and installed at 3 m, the level will be exceeded already at 3.8 m for 15 deg. and at 11.3 m for 3 deg. tilt.

Too close an installation of three Tx antennas may be a disadvantage because of environmental protection reasons (Fig. 3 shows such an example). The distance between the antennas of a given sector is 4 m. As a result of superposition, a stronger EMF appears in the area between the two antenna directions.

For directional antennas, the horizontal range of the area with exceeded admissible radiation level, is the distance of 10–25 m (from the geometrical centre of the antenna) (5).

THE CHARACTERISTIC OF MINI-LINK ANTENNAS (WIRELESS COMMUNICATION)

There are different types of microwave radios/mini-links installed in Transmission BASE STATIONS and GSM BASE STATIONS. Different types of parabolic mini-link antennas (about 30 types) are used. They are from 0.3 to 3 m in diameter and work on 7 GHz, 23 GHz and 38 GHz with the gain from 34.0 to 44.5 dBi. The main lobe may be between 0.7° and 3.7° and output power (from 0.03 W to 1.2 W) differs depending on whether radio units have integrated antenna or separate antenna for which power has to be supplied via wave guides. Practically, there are no power losses for the radio units with integrated antenna, for separated antenna there are, for example, feeder losses of 4.4 dB/100 m for 7 GHz on EW 52 feeder type (4).

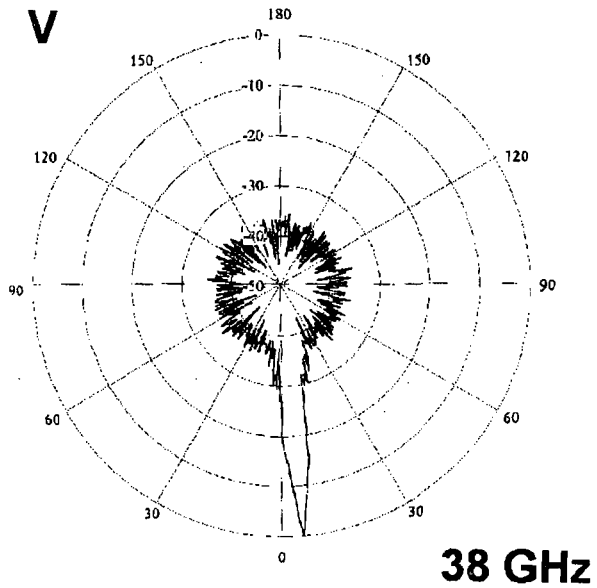
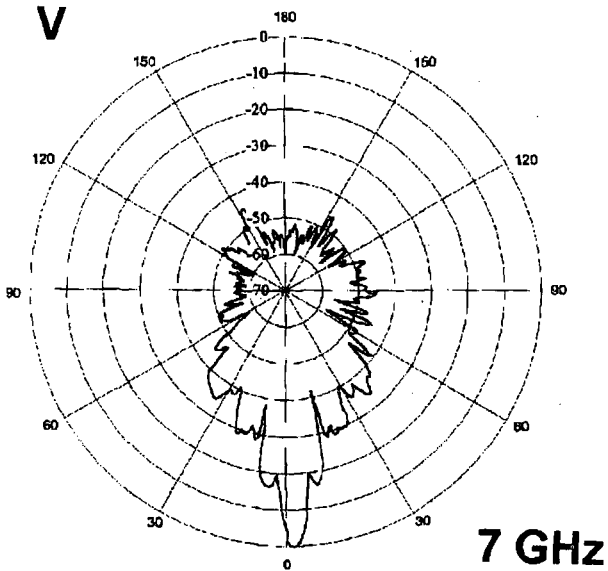
Mini-link antennas work in specific directions. Their beam of radiation is so concentrated that a few degree deviation from it results in almost 30 dB attenuation. Fig. 4 shows vertical characteristic of mini-link antennas as measured in the near field by the Military Institute of Armament Technology (WITU) in Zielonka n/Warsaw.

INTERPRETATION OF THE RESULTS OF THE MEASUREMENTS OF ELECTROMAGNETIC FIELD IN THE SURROUNDINGS OF GSM BASE STATIONS

There have been 20 measurement reports of the actual EMF pattern analysed in the surroundings of GSM BASE STATIONS. Measurements of mean power density have been performed by the authorized institutions (Industrial Institute of Telecommunication (PIT), Warsaw, and The Nofer Institute of Occupational Medicine (IMP), Łódź) according to relevant procedures and current methodical and hygiene standards (1,6,7).

Antennas installed on the buildings

The results of the EMF measurements showed that for 15 BASE STATIONS (rooftops), including 7 residential buildings with the electric centre of the antenna 5.45–8.5 m above roof level (1.65 m in one case), 3.0–4.55 m above the penthouse level, antenna tilt 0° – 9° , the admissible radiation level was exceeded on the roof or at the penthouse level only in 20%.



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Fig. 4. Vertical characteristic of mini-links antennas for the range from 7 GHz to 38 GHz — measurements (WITU, Zielonka).



The values measured for power density varied between less than 0.025 to 2 W/m^2 . For the antenna height of 1.65 m above the terrace level (from the geometrical centre of the antenna) the highest values were found in the closest vicinity. The side of the antenna was facing the edge of the terrace.

There were no measurable power density values either in the containers, cabinets with the transmitting and operational equipment or in their surroundings and along feeders.

There were no measurable power density values on top storeys of the buildings with BASE STATION antennas. In the surrounding buildings and at the levels people might be present, no measurable power density values were found, except for two cases. In one case, the values measured on the balconies of the top storey of the building 40 m from the BASE STATION ranged from 0.018 W/m^2 to 0.023 W/m^2 , in the other, the values up to 0.034 W/m^2 were found in the horizontal plane of the windows in the building 52 m away from the BASE STATION. These values were over 3 times lower than the maximum admissible levels.

Antennas mounted on towers and chimneys

There were no measurable power density values in the surroundings of three towers with GSM BASE STATION antennas. The measurements on the ladder of one tower about 1.5 m behind the antenna showed EMF of 0.06 W/m^2 , however,

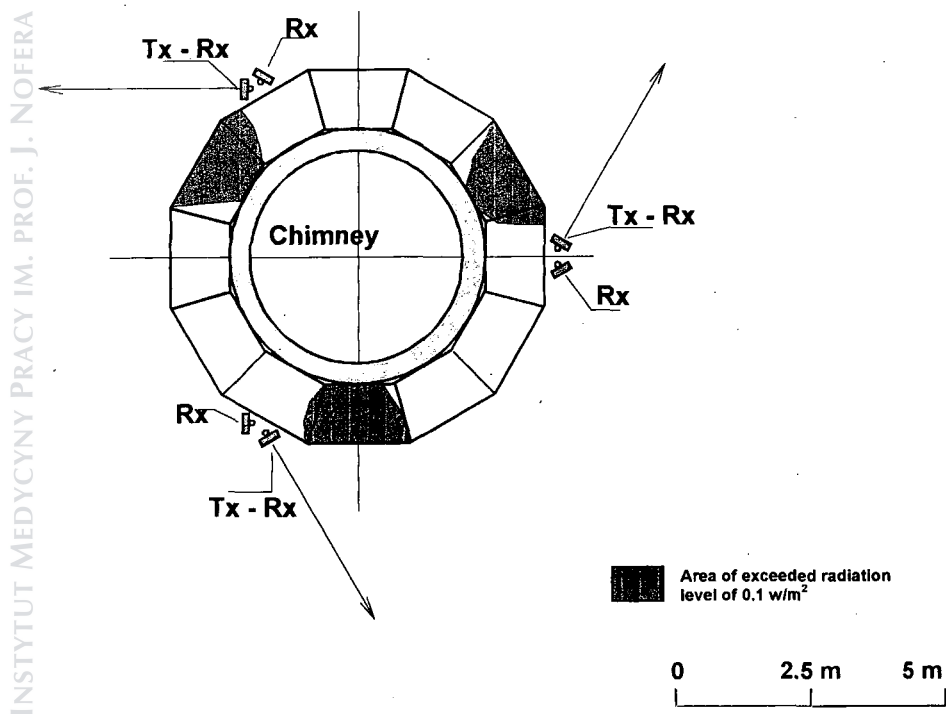


Fig. 5. Pattern of the radiation level on the gallery of the chimney of power and heat generating plant for the directional antennas of GSM BASE STATION, defined on the basis of the measurements performed by The Nofer Institute of Occupational Medicine, Łódź.

on the bridge of the same tower 2 m below the antennas the value increased to 0.66 W/m^2 . Authorised workers only have the access to those locations, and the values correspond to intermediate and safe zones.

There were no measurable power density values in the surroundings of three chimneys of power and heat generating plant with GSM BASE STATIONS antennas. The measurements on the gallery of one of them (antennas mounted on the brackets) showed the highest value of 1.7 W/m^2 (intermediate zone). Fig. 5 presents the area where the environmentally admissible level was exceeded. For the other two chimneys, the values ranged from 0.021 W/m^2 to 0.54 W/m^2 . It is the workers dealing with the chimney maintenance, including electricians changing chimney indicators, that have access to the stages of the chimney.

MICROWAVE RADIO ANTENNAS

There have been 39 measurement reports analysed of the parabolic microwave radio antennas installed in 18 GSM BASE STATIONS (1,6,7). The antennas were mounted at the height of 1.0 m to 5.9 m above the roof and the penthouse level. Owing to the type of mounting (in the majority of cases the face of the antenna was beyond the roof or penthouse edge) and very narrow directional beam of radiation, the measurements were extremely difficult or almost impossible. Since additional mini-links are very often installed on operating BASE STATIONS, the workers might be within the radiation range of operating antennas. Laboratory measurements of the most commonly used antennas for 7 GHz, 23 GHz and 38 GHz were performed in the near field (8). The measurement results indicated that power density values in the antenna near the field was decreased, oscillating around the medium value reaching maxima and minima. In Fig. 6 there can be found the pattern of microwave power density in the antenna beam axis for the frequency of 38 GHz. The strongest power density, i.e. 0.268 W/m^2 was measured 0.5 m and 1.5 m away from the antenna beam axis. The results of the measurements for vertical axis in the near field for 7 GHz antenna, 0.6 m in diameter and radio unit output power of 0.63 W, indicated dangerous zone 0.35 m wide, and an intermediate zone 1.02 m wide 5 m away from the antenna. In comparison,

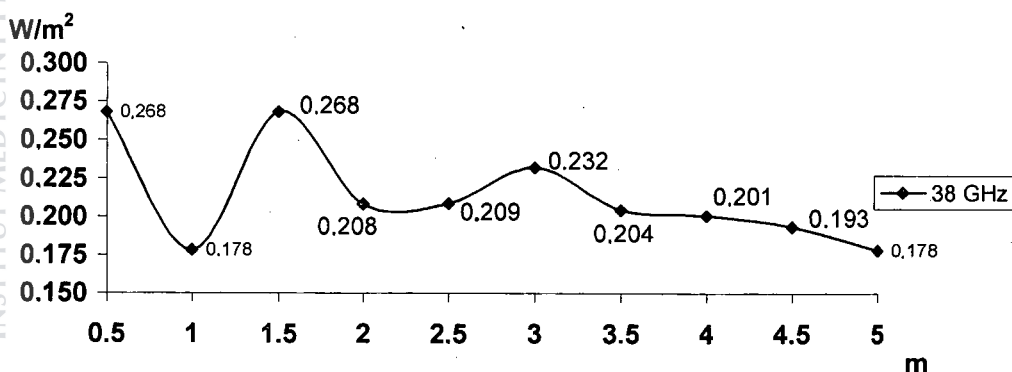


Fig. 6. Microwave power density on the antenna beam axis 38 GHz, 0.6 m, 20 dBm – measurements performed by The Nofer Institute of Occupational Medicine, Łódź.

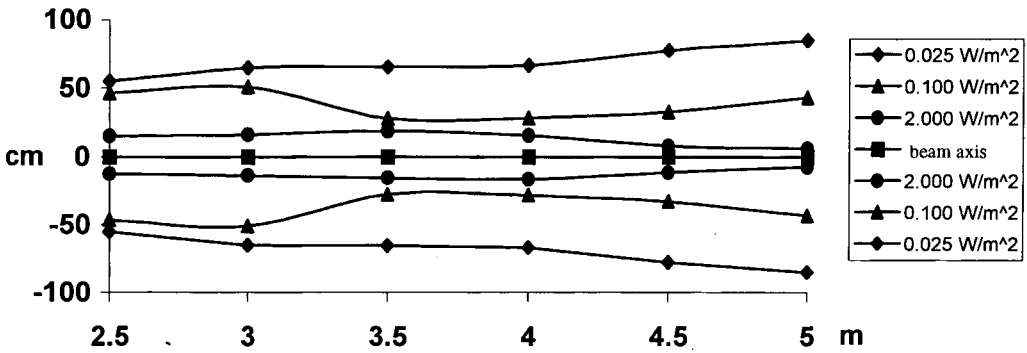


Fig. 7. Pattern of radiation level in antenna near field 7 GHz – vertical section – measurements performed by The Nofer Institute of Occupational Medicine, Łódź.

analogical measurements of horizontal plane showed the width of protection zones of 0.3 m and 1.82 m for the above mentioned distance. The pattern of the protection zones in antenna near field 7 GHz, vertical section, can be found in Fig. 7. There was 17 m far field range for 7 GHz antenna, 0.6 m in diameter. The protection zones, were: dangerous zone within 5.4 m, intermediate zone within 25 m.

CONCLUSIONS

1. All the transmitting equipment for the mobile telephone network of the GSM system, and Rx and TxRx antennas in particular, generate EMF in microwave range, thus, they are subject to laws binding in Poland.

2. The analysis of the documents regarding technical solutions and physical parameters of equipment installed in existing BASE STATIONS indicates that except for a few cases, the equipment meets the requirements for the protection of people and environment.

3. On the basis of the EMF measurement reports for 20 BASE STATIONS, it was found that:

(a) for rooftop mounted antennas the admissible radiation level was exceeded in 20% of locations (twice at the penthouse level and twice on rooftops).

(b) for the antennas mounted on towers and chimneys of heat and power generating plants the admissible radiation level was exceeded in 5% of locations.

4. According to the EMF measurements, there are no protection zones in the accessible surroundings of mini-link antennas.

5. The laboratory EMF measurements in the surroundings of the most commonly used mini-link antennas showed that the admissible EMF environmental levels in their near surroundings were exceeded (dangerous and intermediate zones were found to be related with occupational exposure). For 7 GHz mini-link antennas the width of protection zones exceeded several times the antenna diameter.

6. Admissible EMF intensities at the level of people's presence, in existing buildings, in surroundings of BASE STATIONS and inside buildings with antennas, were not exceeded.

7. The protection zone area on rooftops and at the level of penthouses, as well as on stages and bridges of towers, and heating and power generating plants is easily accessible to public. The workers repairing or maintaining rooftops, facades etc. are allowed to stay in the area only if admissible level of radiation is not exceeded.

8. Workers dealing with exploitation and maintenance of transmitting equipment of the GSM network may be exposed to EMF only if its value corresponds to the limits in dangerous and intermediary protection zones.

9. Mini-link antennas should not be mounted on rooftops and at the level of penthouses at the height lower than 2 m (the bottom of the antenna) for 23 GHz and 38 GHz and not lower than 3 m (the bottom of the antenna) for 7 GHz, if their beam of radiation is found in an easily accessible part of the building or penthouse roof.

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