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# Base station antenna near-field radiation pattern distortion analysis

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## Abstract

When estimating the potential radiation hazard of a base station antenna system, one often relies on the antenna far-field radiation pattern, while the estimation often refers to the antenna near-field zone. It is widely accepted that this leads to overestimation of the field amplitudes. Some recent works suggest the use of modified analytical models to avoid the overestimation problem. However, all of these references refer only to a single antenna in the free space. This work shows that potential near-field radiation pattern distortion due to conductive objects in the close proximity of the antenna (like in multiple- antenna configuration) makes many models inapplicable. In that case, in the directions outside the mainlobe of the antenna, sidelobes are shifted and changed in an unpredictable manner. The nulls are either shifted, or filled so they do not really exist. The mainlobe itself can get an additional gain of a few dB in unpredictable directions. This suggests that even the use of the far-field pattern can sometimes lead to underestimation of the field. Considering that many real antennas have some conductive object nearby, especially in multiple antenna configurations, this work suggests that for truly conservative, worst-case electromagnetic field estimation, far-field pattern should be used for the mainlobe, with the uncertainty of a few dB. For all other directions, the protective envelope should be used as the radiation pattern, with the gain in all directions equal to the highest sidelobe gain. No nulls should be considered to exist in the near field radiation pattern.

## 1 Introduction

Base station antennas are nowadays regarded as important contributors to the electromagnetic pollution. The reasons are many: penetration in the populated

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areas, eye-catching visual impact, all-round awareness due to mobile telephony penetration. Consequence is that national authorities issuing the installation permission demand electromagnetic field hazard estimation prior to base station installation.

The essential information needed for this job is the antenna radiation pattern. Engineers and scientists are forced to rely on data provided by antenna manufacturers and constructors of the BTS site. Since antennas are primarily intended for EM field coverage of the wide areas in the far-field zone, neither the manufacturer nor the constructor are interested in the near-field antenna specifications. Not only the matter of interest, but also the near-field antenna pattern is more difficult (expensive) to measure or calculate. It is also more complicated to express, because it changes with the distance from the antenna. As the result, only the far-field pattern is obtainable.

On the contrary, the EM field estimation is most interesting in the near-field zone of the antenna. With the present maximum permissible exposure limits, field values in the far field of today BTS sites (GSM base stations in Croatia: EIRP less or equal 1kW per channel, max. 6 channels per sector) are below the limits. So the near-field zone is what really counts.

## 2 EM field estimation using the provided far-field antenna pattern

Directional base station antennas, that this analysis refers to, are intended for EM signal coverage of a sector area. The horizontal plane around the BTS site is divided usually to three sectors, each covered by its own antenna and radio channels, to increase the network capacity. Thus, the antenna mainlobe should cover around 120° in horizontal plane.

It is not of any use to radiate the energy upwards in the space, or to create strong signal directly beneath the antenna. This means that the antenna mainlobe in the vertical plane should be narrow and directed to or below the horizon, depending on the terrain configuration.

Field amplitude or power density can be calculated with the analytical equation:

$$S = \frac{P \cdot G(\varphi, \vartheta)}{4R^2\pi} , \tag{1}$$

where $S$ is power density, $P$ is output power, $G$ is gain (function of azimuth and elevation angles), $R$ is distance from the antenna. After the area of interest is located, its relative position with respect to the antenna is expressed with the distance, azimuth and elevation, and power density is calculated using the gain extrapolated from the far-field radiation pattern supplied by the manufacturer. For the worst-case analysis, the shortest distance to the area of interest should be used. Also, the maximum gain in the space angle covering the area of interest should be used. The calculated result should be multiplied by the number of channels $N$, assuming the possibility of all channels radiating maximum power, (which almost never happens). Finally, if the field near some flat surface is needed, it is possible that the reflection can cause almost the doubling of the field. Some references (like [6]) suggest a realistic factor of 1.6 times increase of the field, which leads to 2.56 times increase of the power density. Equation (1) is then modified:

$$S = \frac{2.56 \cdot EIRP \cdot G(\varphi, \vartheta) \cdot N}{4R^2\pi}. \tag{2}$$

Antenna patterns supplied by the manufacturers typically show the far-field azimuth and elevation patterns. Three-dimensional gain needed in equation (2) cannot be easily extrapolated from these patterns. Thus, even the far-field is not specified in detail.

Equations (1) and (2) are valid in the far-field region or for worst-case analysis, so the far field condition must be checked with the well-known equation for near-field to far-field boundary $R_{FF}=2D^2/\lambda$, where $D$ is the largest antenna dimension and $\lambda$ is wavelength. Calculated distance $R_{FF}$ is about 24m for typical antenna dimension of 2m.

If ICNIRP general public permissible exposure limit (PEL) for GSM frequency is chosen (4.675W/m$^2$, i.e. 42V/m), analytical far-field calculation shows that the PEL accomplishing distance in the mainlobe, for 1kW EIRP and 6 channels in sector, will be around 16m. Outside the mainlobe, in the sidelobes direction, if sidelobe suppression is 15dB, $R_{PEL}$ decreases to about 3m. If the area of interest lies in the nulls of the radiation pattern, every distance from the antenna should be safe. If PEL decreased to e.g. 6V/m, $R_{PEL}$ would be 112m in the mainlobe, 20m for the sidelobe suppressed for 15dB, and nulls would become very important.

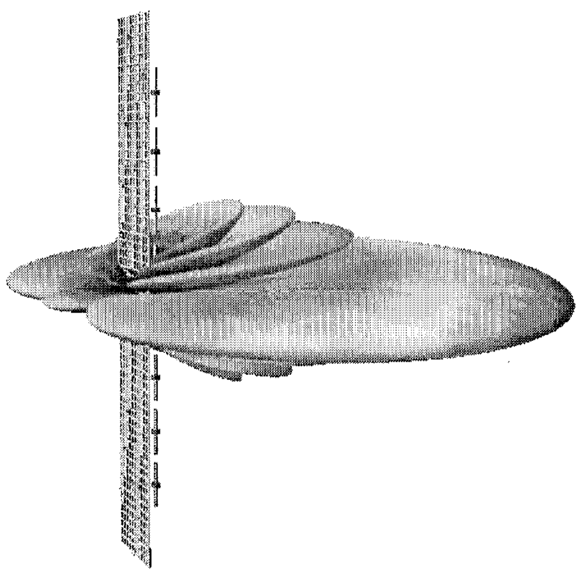

Figure 2: 3D view of calculated far-field pattern of base station antenna in free space

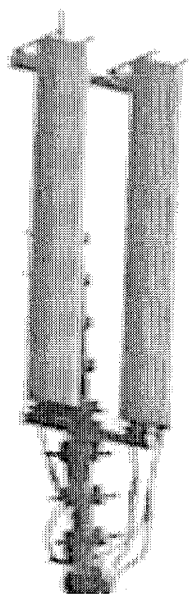

Figure 3: see text

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## 3 Base-station antenna in free space radiation pattern analysis

The described antenna characteristics are achieved using vertical array of $\lambda/2$ dipoles, spaced by $0.6\lambda$ to $1\lambda$, placed in front of a reflector. Specific antenna with 8 dipoles spaced by $0.6\lambda$ is analyzed here, with uniform distribution of feed currents and $0.25\lambda$ spacing from reflector. The method-of-moments numerical computation of the EM field around this antenna was done using NEC2 engine [5] with the help of 4NEC2 software. Visualized calculation result can be seen in Figure 2. All NEC calculations were done with 100W of antenna input power.

This kind of pattern analysis is common and yields the results very similar to the manufacturer specifications. This calculation was done using the far-field pattern approximation, and is valid in the far-field zone of the antenna.

To check for the near-field phenomenon, the same method of analysis was used to obtain the near-field values of electric field. The near electric field was calculated along the -90°, 0° and +90° azimuth axes of the antenna, at the heights from -10m to 0m from the antenna, with the resolution of 0.05m (see Figure 3). The calculation was done up to 10m distance from the antenna, with 0.05m step. This was due to processing time limitations, but also due to assumption that the pattern distortion would be greatest (therefore of most interest) close to the antenna. The idea was to compare true near fields to the fields calculated using the far-field pattern. The comparison was done at the heights of 0m, -5m and -10m, with 0.5m step. The fields at the heights of -5m and -10m from the antenna are interesting for checking for the rooftop exposure beneath the antenna installation. Results are shown in Figure 5 and Figure 6.

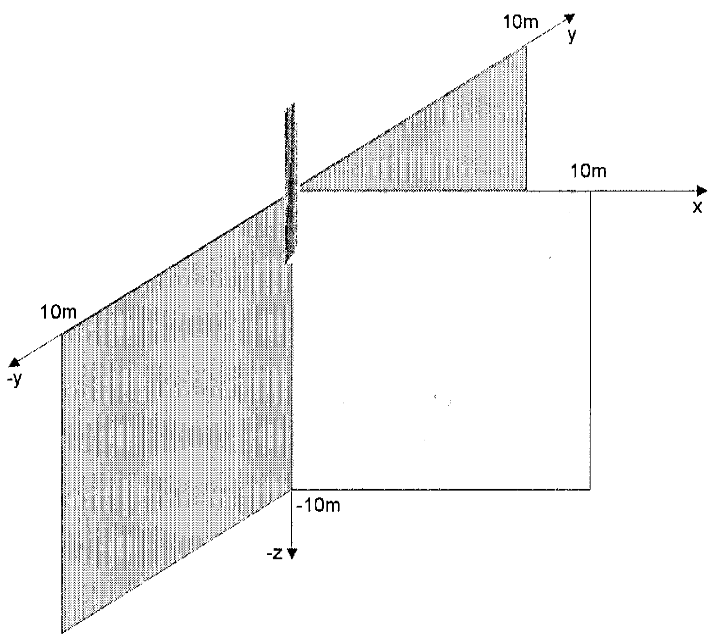


Figure 4: Areas of near electric field calculation

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# 4 Real base station antenna radiation pattern analysis

In the real life, antenna is not placed in the free space. It is not only backed by a pole, wall or other structure, but also surrounded by other conductive objects in the immediate vicinity. The more the object penetrates into the antenna main lobe, more deviation it will cause in the antenna radiation pattern.

Of course, blockage of the radiation is avoided as much as possible by GSM operators. Still, there are BTS site antenna configurations that intendedly put antennas close to each other in a way that can cause pattern deviations. In fact, it is a rare situation, especially in urban areas, where only one antenna is used per sector. Multiple antennas per sector are used when there is a need for polarization or space diversity of the signal reception. Sector can be covered by different combinations of transmit (TX), receive (RX) or combined (TX/RX) antennas. Antennas can be vertically or horizontally polarized, or cross-polarized with two sets of dipoles in the same antenna enclosure (radome). Antennas are placed usually at the same height. Usual combinations are:

- one vertically polarized TX antenna and 2 RX antennas (horizontally and vertically polarized);
- one vertically polarized TX/RX antenna and one horizontally polarized RX antenna;
- one cross-polarized TX/RX antenna.

Antennas are in these cases spaced by a few wavelengths, most often by $2\lambda$.

Even more interesting is a new practice of covering a sector using two TX/RX antennas. The idea of this configuration is to minimize the losses in the combiner. Where there is more than 1 channel in one sector, all channels should add up passing through the RF combiner to be radiated by a single antenna. The combiner has the insertion loss of a few dB. More channels in one sector mean more combiners or more losses. When the number of channels exceeds three, it is more convenient to use more antennas than more combiners, to conserve energy and minimize losses. In this case, the practice is to space antennas close to each other. Due to mechanical considerations, operators often try to place them as close as possible. The limit is only to prevent the saturation of the receiver of the first antenna with the transmit signal from the other antenna and vice versa. This means that the spacing is arbitrary and it usually varies from 0.25m to 0.4m. Figure 3 shows real life configuration of multiple antennas per sector.

Such antenna configuration was analyzed using the same method of calculation (NEC2 with 4NEC2). Configuration consists of two same antennas, placed close to each other. Spacing between them varied from 0.25m to 0.4m (with the 0.05m step) to observe the influence of spacing to antenna pattern distortion. One antenna was radiating, while the other served only as the scattering object in the near field. Far-field patterns were calculated. Near-field values of electric field were computed along the same axes as in the free space analysis. Figures 5 and 6 show the comparison of all calculated results.

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# 5 Comparison of the results for free space to the real antenna configuration

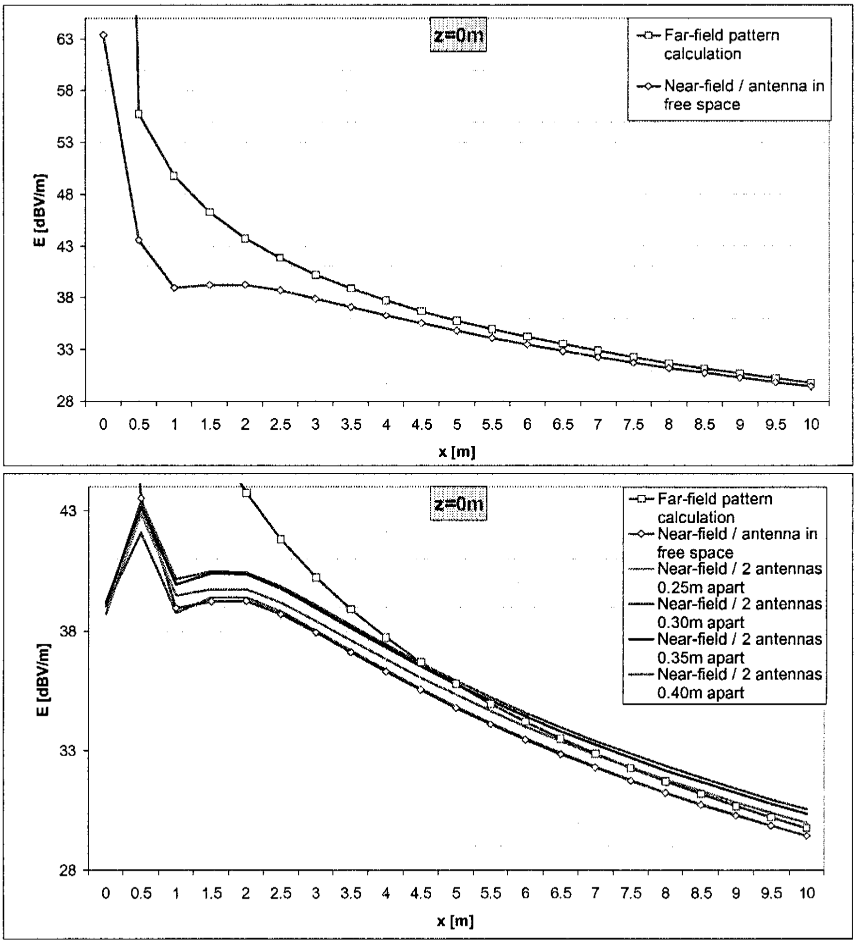


Figure 5: Calculated fields comparison

Looking at the near-fields comparison, the greatest difference between them can be observed where the lowest fields are expected - in the nulls of the radiation pattern. Those values vary considerably. Values in other points of space are also subject to variations of a few dB. This can clearly be seen on the far-field patterns (Figure 6), which differ by almost 3dB in the mainlobe. Variations greater than that can be expected in some points of the near-field zone.

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## 6 Conclusion

This analysis was done for a specific case of two GSM BS antennas very close to each other. The results show significant impact on radiation pattern distortion, especially in the near-field zone. This leads to the uncertainty of EM field estimation for GSM BS antennas in this configuration, but also in other possible configurations with objects in the immediate vicinity of TX antenna. Since it would be impossible to accurately analyze every possible situation, some guidelines should be adopted for EM field estimation. Graphical results show that nulls must be disregarded in the distorted pattern.

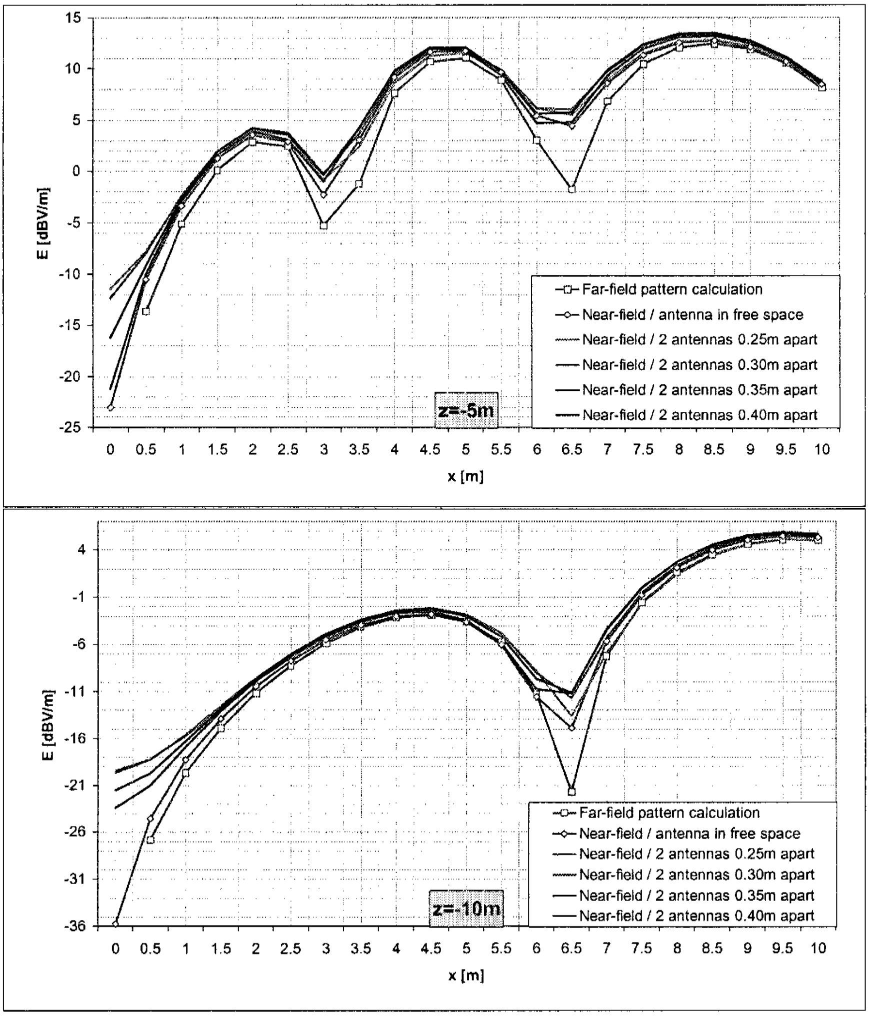


Figure 5: Calculated fields comparison (continued)

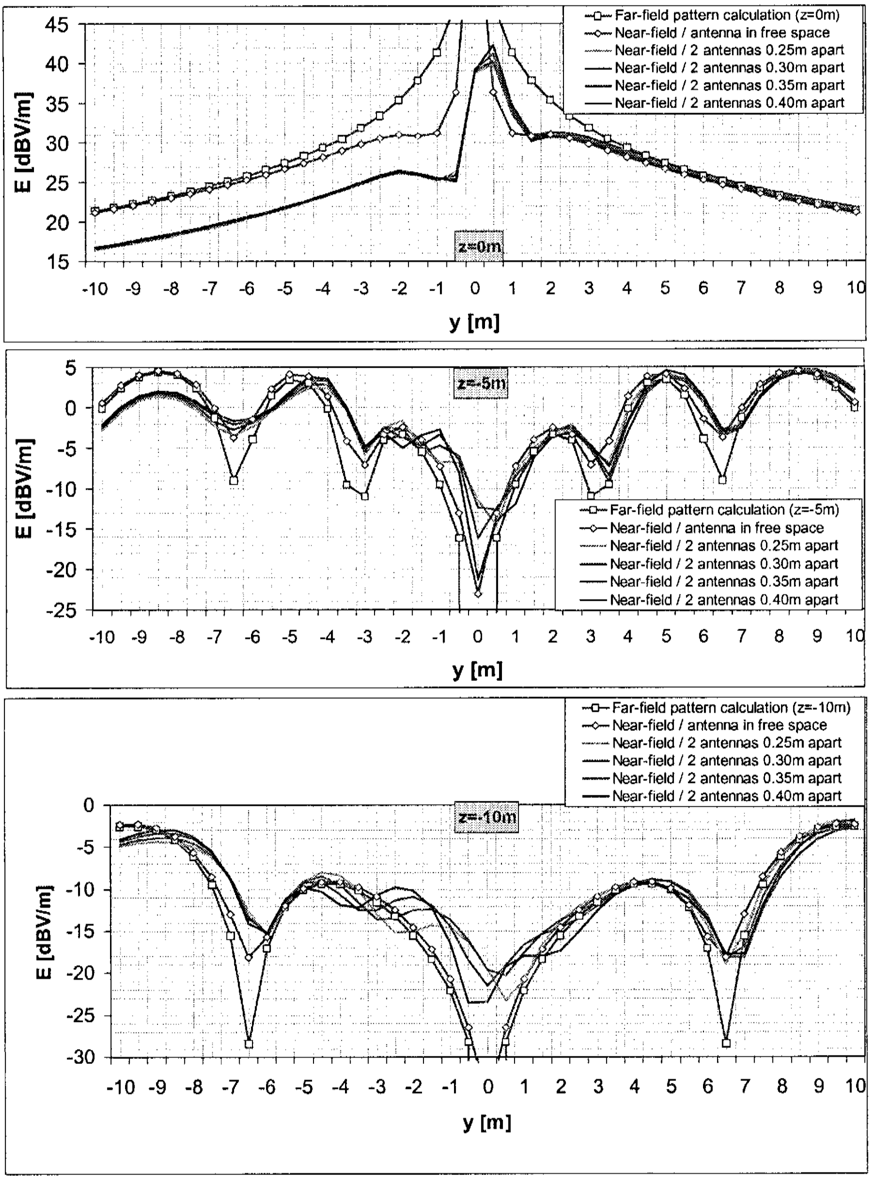


Figure 5: Calculated fields comparison (continued)

Due to pattern uncertainty, protective envelope should be used instead of radiation pattern, for EM field estimation outside the mainlobe. The envelope should connect all the sidelobe peaks. When estimating EM fields in the mainlobe, far-field pattern can be used. Mainlobe pattern and protective envelope should be connected to a new, "worst-case" pattern.

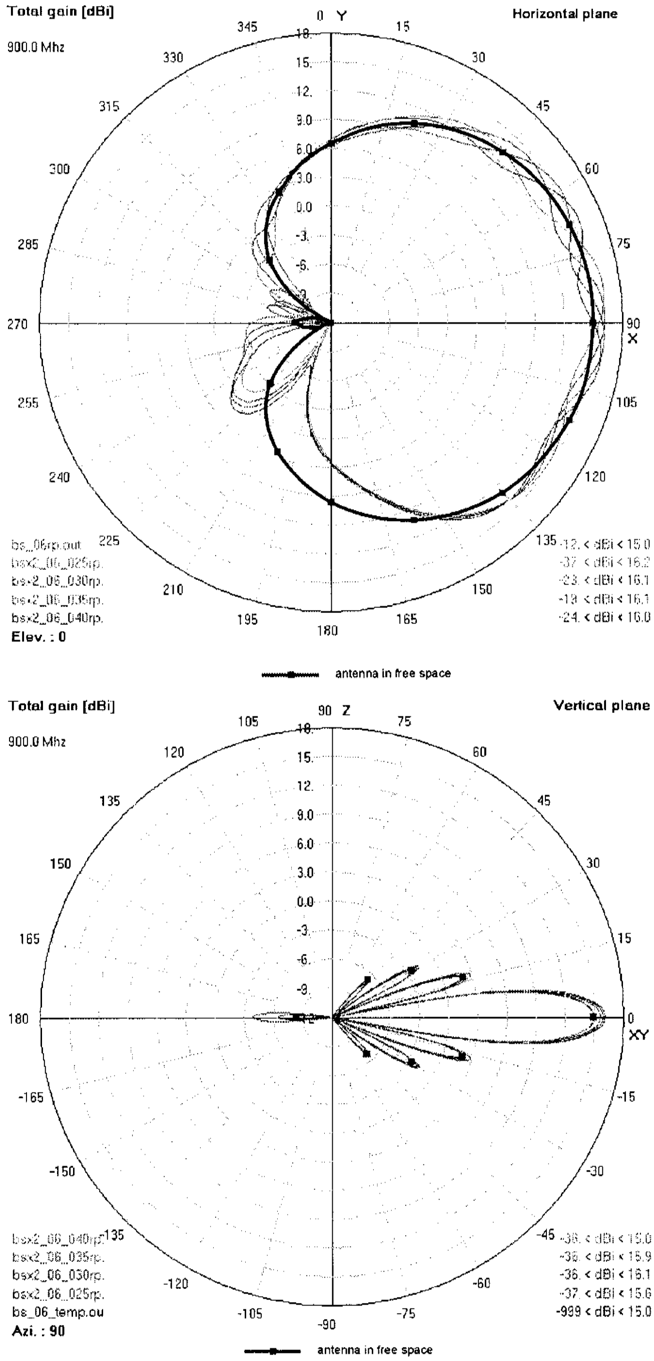


Figure 6: Calculated far-field antenna patterns

The results show that using the far-field pattern even in the mainlobe (see Figure 5, z=0 and Figure 6) can yield underestimation of the field of approx. -2dB for this configuration. These 2dB should be added to the "worst-case" pattern or stated as the estimation uncertainty.

Since this analysis was time-limited, more extensive analysis will be done with more possible configurations, different antenna parameters (dipole spacing, feed currents distribution), and for wider area around the antenna. However, these results show the potentials for EMF estimation uncertainty that was not accounted for in previous works.

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