Installation Uncertainty of Field Level Calculation around a Base Station Antenna

Antonio Šarolić and Borivoj Modlic

Abstract: **In the near field, the antenna pattern provided by the antenna manufacturer is generally not applicable, or should be considered with caution, even for the single antenna in free space. In the real life, antenna is often surrounded by other conductive objects in the immediate vicinity. These objects tend to distort the antenna radiation pattern. Since the electromagnetic field calculation for the coverage or radiation hazard analysis depends on the three-dimensional antenna gain, this effect should be taken into account. This paper suggests the use of "installation uncertainty" that should be added to the field calculation. The amount of this quantity depends on the installation geometry and can be calculated numerically for a specific situation. This paper shows the results of numerical calculations for some typical antenna installation geometries.**

Index terms: **radiation hazard, base station antenna radiation pattern, near field**

I. Introduction

The radiation pattern is the basis for the electromagnetic field calculations for various purposes, e.g. coverage estimation and radiation hazard (RADHAZ) analysis. When planning the base station coverage in stringent circumstances, every decibel is important. Uncertainty of a few dB could mean a lot for such a calculation. Such uncertainty is also significant for the base station compliance to the human protection standards.

Due to the increased awareness of EM pollution, national authorities issuing the base stations installation permits demand RADHAZ estimation prior to base station installation. This estimation is based on field level calculation around the base station.

The essential information needed for this job is the antenna radiation pattern. Engineers and scientists are forced to rely on the data provided by antenna manufacturers and constructors of the base transceiver station (BTS) sites. 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 a 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. For this reason, it should not even be called "pattern", but rather the "EM field distribution". As the result, only the far-field pattern is obtainable.

Fig. 1. Installation examples

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

Analytical calculation formulas use the antenna gain as a function of azimuth and elevation. If calculation is done for the far field, the radiation pattern is used. If calculation is done for the radiating near field, radiation pattern can be used with some caution. In the reactive near field, fields can only be calculated numerically, knowing the exact geometry of the antenna itself (including the feed currents distribution) and its installation. If these calculations are done using far field pattern of the single antenna in free space, neglecting the installation geometry, results will not be accurate. Depending on the antenna environment, the error could be as high as few dB, as this analysis shows.

The conductive objects in the vicinity of the antenna distort the radiation pattern [1-7]. To our knowledge, this problem is not addressed in references on electromagnetic field calculation around base stations. In another words, all references refer to the single antenna in free space (e.g. [9-11]).

In the real life, antenna is often placed near another antenna, wall, pole, or other structure. Moreover, it is in fact a rare situation in urban areas where only one antenna is used per sector. Multiple antennas per sector are used whenever there is a need for polarization or space diversity of the signal reception.

Sometimes the stringent circumstances dictate that antenna must be placed in the vicinity of other conductive objects: rods, poles, cables, other services antennas etc. as shown in Fig.1. The distortion can then be significant.

The deviation of the supplied radiation pattern from the real, distorted pattern becomes the error. Since its value is generally unknown, the error becomes the uncertainty that we call ***installation uncertainty***.

The object of this research is to demonstrate installation uncertainty for some typical cases of installation geometry, with respect to the far-field and near-field levels calculation.

II. FAR-FIELD CALCULATIONS

A. Far-field calculation procedure

To demonstrate the effect of pattern distortion, the electric fields around a typical base station sector antenna were numerically calculated. The antenna was situated in free space without obstacles to obtain the radiation pattern that corresponds to the one usually supplied by the manufacturer. Then the antenna was placed nearby a typical conductive object, side by side: rod, 2 rods, panel and another antenna of the same type and size, like in multiple antennas configuration. The distance from the antenna to these objects varied from 1.5λ through 1.75λ to 2λ.

The antenna and the objects were modeled by wiregrid models. The fields were then calculated by the Method of Moments, using the NEC2 software [8]. The analyzed antenna was a theoretical model of a common vertically polarized GSM sector antenna, consisting of an array of dipoles in front of a metal reflector. A configuration of 8 vertical dipoles spaced by 0.75λ (Fig.2.) was chosen. The distance from the reflector was 0.25λ.

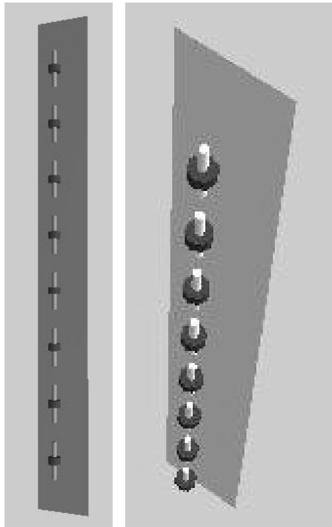

Fig. 2. Single antenna in free space

B.Far-field calculation results

Fig.3. to Fig.8. show the antenna configurations with the summary of effects. Only horizontal patterns are shown because vertical radiation patterns exhibit only minor changes. This is understandable due to obstacles placed horizontally with regards to the antenna.

Figures show that the installation uncertainty of side-by-side configurations can rise as high as 1.5 dB or 2 dB through the main lobe at the worst case. Moreover, the difference between maxima and minima throughout the main lobe can reach more than 3 dB. In fact, the main lobe becomes divided into two or three segments.

Figures show that the distortion form and direction depend on the distance from the antenna to the obstacle. The magnitude of the distortion is approximately the same for all three distances chosen. We did not calculate for the distances smaller than 1.5λ because such installations are generally avoided due to effects of receiver saturation. On the other hand, distances greater than a few λ from the antenna to the obstacle would cause less distortion and are not as interesting.

Less distortion is to be expected also if the obstacles are placed more behind the antenna, not side by side with the antenna, but, greater distortion can be expected with the obstacles more in front the antenna. Of course, the latter is generally avoided, but sometimes is inevitable.

The distortion of the radiation pattern can obviously lead to underestimation and overestimation of the field levels when using the manufacturer provided pattern. With provided geometry and antenna details, pattern distortion, or better said, the real radiation pattern can be numerically calculated for virtually any situation. Of course, such calculations can vary in complexity.

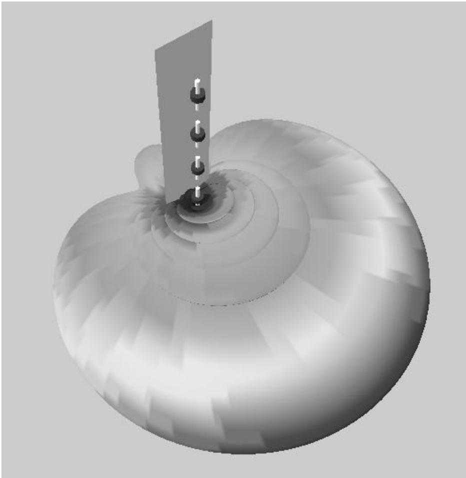

Fig. 3. A single antenna radiation pattern

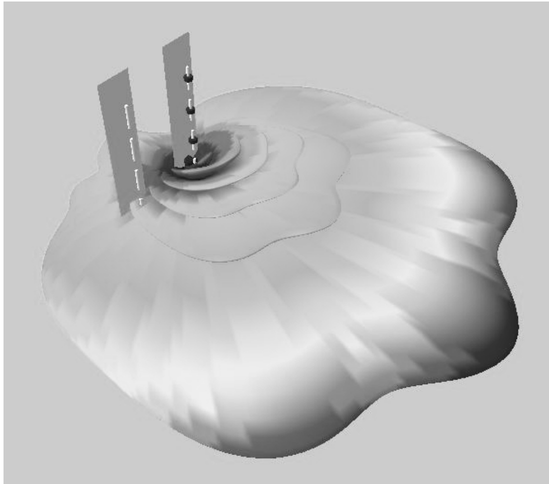

Fig. 5. Distorted pattern of two antennas side by side

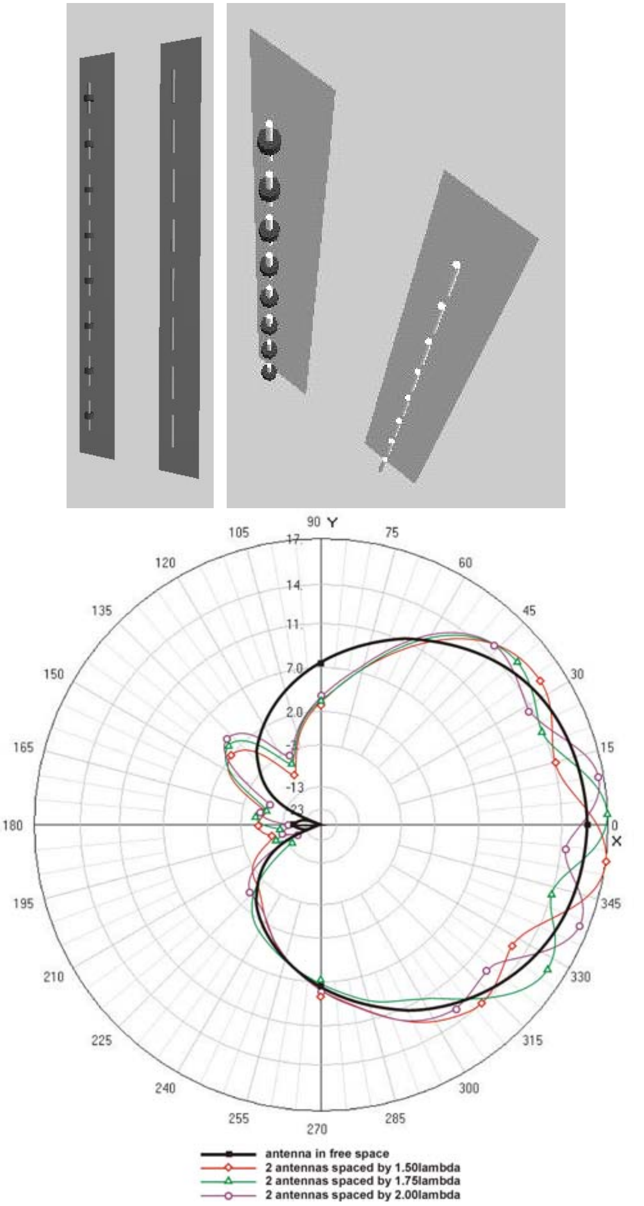

Fig. 4. Antenna in free space vs. 2 antennas, calculated horizontal radiation pattern distortion of about 1.5 dB throughout the mainlobe, about 4 dB gain decrease in the direction of the obstacle

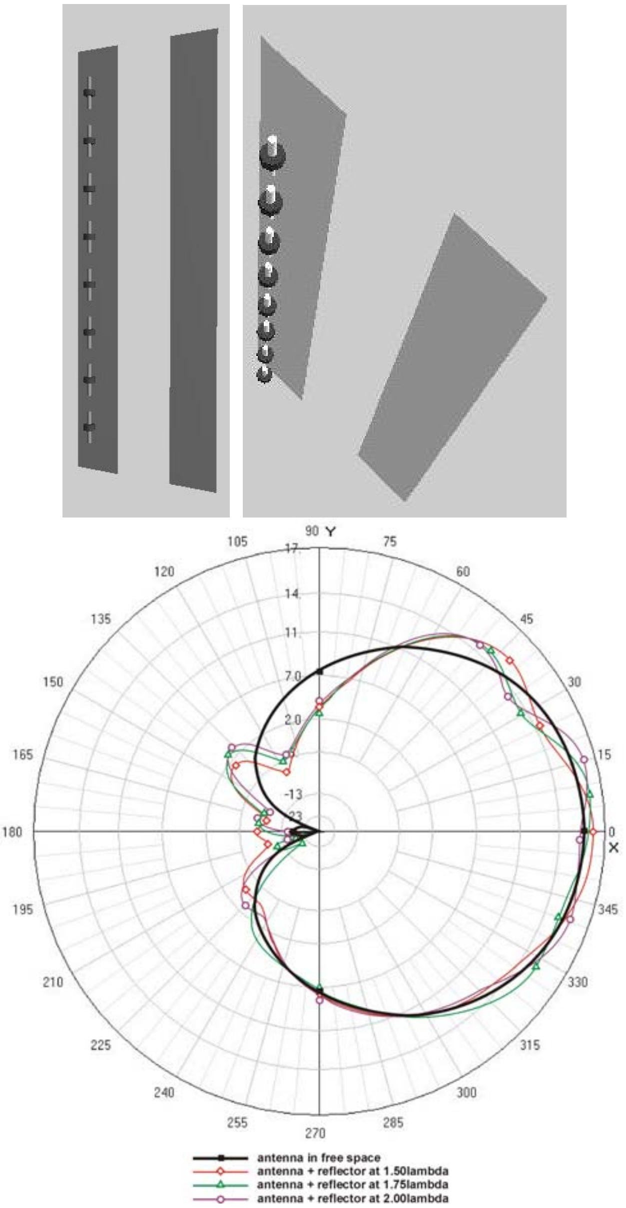

Fig. 6. Antenna in free space vs. Antenna + reflector, similar but slightly less distortion than for the previous configuration

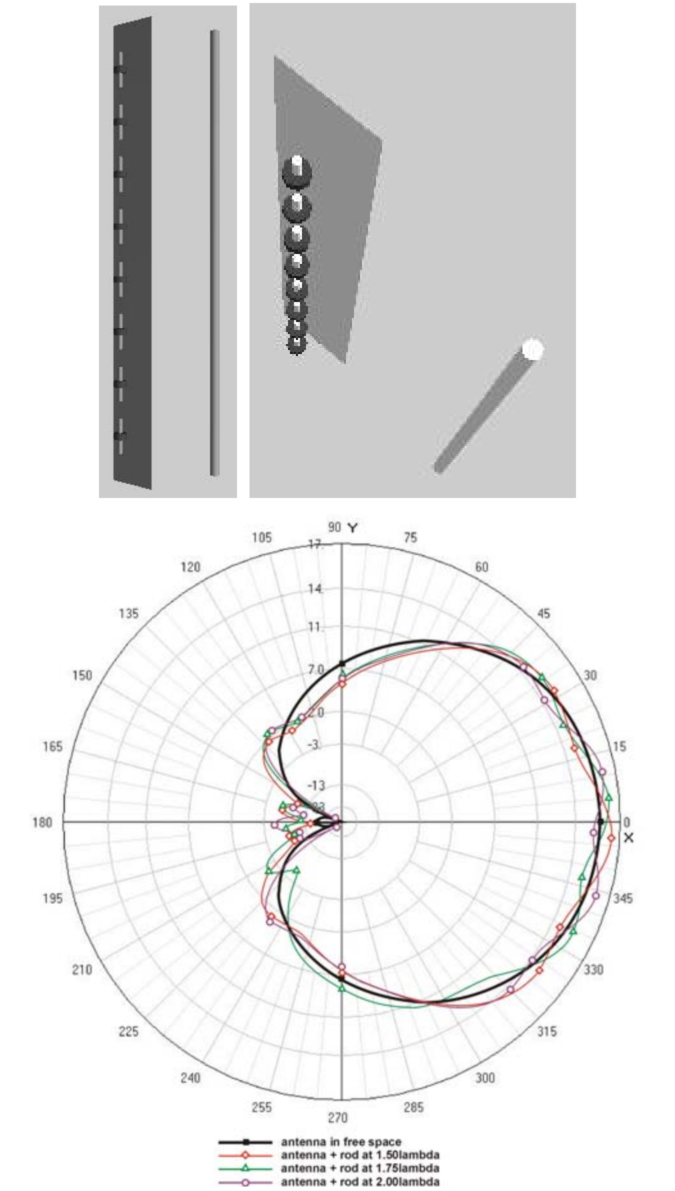

Fig. 7. Antenna in free space vs. Antenna + rod, calculated horizontal radiation pattern distortion of about 1 dB in all directions

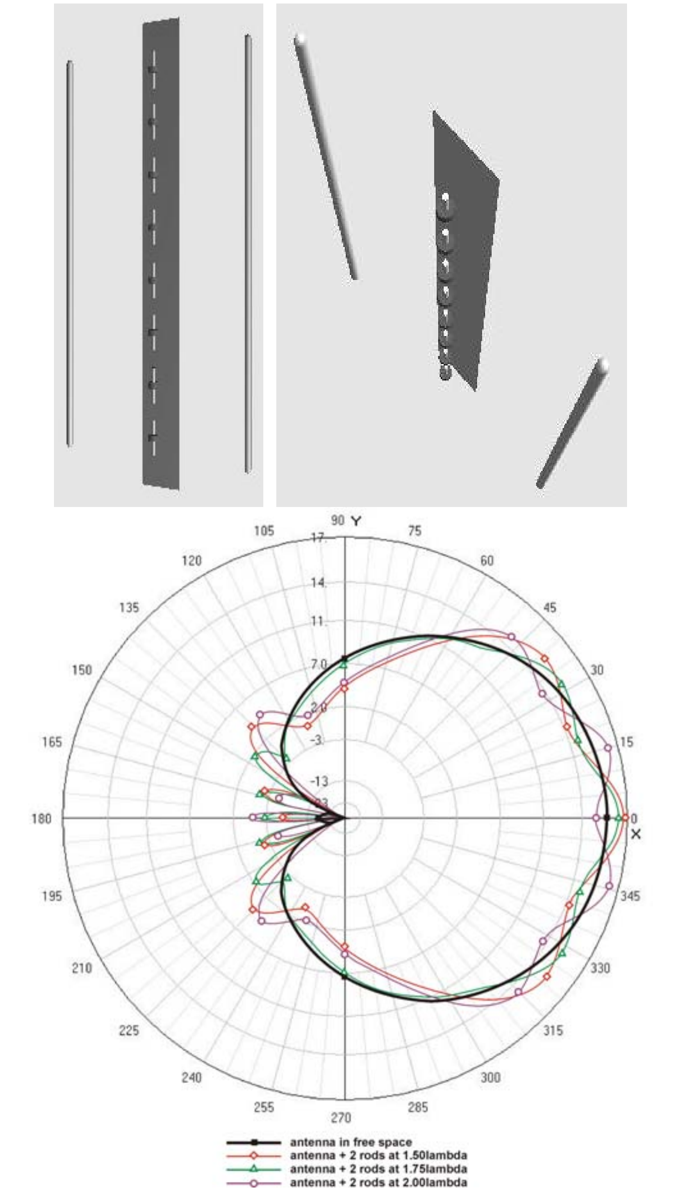

Fig. 8. Antenna in free space vs. Antenna + 2 rods, calculated horizontal radiation pattern distortion of about 1.5 dB in all directions

III. NEAR-FIELD CALCULATIONS

A. Near-field calculation procedure

The standard field level calculation procedure follows. After the area of interest is located, its relative position with respect to the antenna is expressed with the distance, azimuth and elevation. The power density is calculated using the gain extrapolated from the far-field radiation pattern supplied by the manufacturer. Field amplitude or power density can be calculated with the analytical equation:

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

where S is power density, P is output power, G is gain (function of azimuth and elevation angles), R is distance from the antenna. 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, to account for the possible deviations from original installation plans.

The calculated result should be multiplied by the number of channels N, assuming the possibility of all channels radiating maximum power (this happens in rare occasions). 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 [12] suggest a realistic factor of 1.6-fold increase of the field, which leads to 2.56-fold increase of the power density. Equation (1) is then modified to equation (2):

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

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 radiating region of the near field, 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 λ is wavelength. For typical antenna dimension of 2 m, calculated distance R_{FF} is about 24 m.

If ICNIRP [13] general public permissible exposure limit (PEL) for GSM frequency is chosen (4.675 W/m^2, i.e. 42 V/m), analytical far-field calculation shows that the PEL accomplishing distance R_{PEL} in the mainlobe, for 1 kW EIRP and 6 channels in sector, will be around 16 m (safe distance). Outside the mainlobe, in the sidelobes direction, if sidelobe suppression is e.g. 15 dB, R_{PEL} decreases to about 3 m. 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. 6 V/m, R_{PEL} would be 112 m in the mainlobe, 20 m for the sidelobe suppressed for 15 dB, and nulls would become very important.

For the near-field analysis, the same antenna described earlier and shown in Fig.2. was chosen. The feeds were modelled as voltage sources (applied electric field sources), placed at the center segment of each dipole. The combined input power of all sources was chosen to be 30 W – a typical maximum power for one GSM channel. The numerical computation of the far field around this antenna was done using NEC2 engine [8] based on Method of Moments. Far-field pattern analysis is common and yields the results very similar to the manufacturer specifications.

To check for the near-field phenomenon, the same method of analysis was used to obtain the near-field values of electric field. The idea was to compare true near fields to the fields calculated using the far-field pattern, looking for the amount of underestimation. The near electric fields were calculated along the -90º, 0º and +90º azimuth axes of the antenna, at the heights from 0 m to -10 m, and at the distances from 0 m to 10 m (measured horizontally), see Fig.9. The 10 m limit was chosen 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 calculation was done with 0.1 m step, and the comparison is shown here only at the heights of 0 m, -5 m and -10 m. The fields at the heights of -5 m and -10 m from the antenna are interesting for checking for the rooftop exposure beneath the antenna installation.

Afterwards, the results for a single antenna in free space were compared to the results obtained for 2 identical antennas placed side by side. This configuration is a new concept of covering a BTS sector using two TX/RX antennas, to minimize the combiner losses. Due to mechanical considerations, operators often try to place the two antennas 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 0.25 m to 0.4 m of space between the antenna housings.

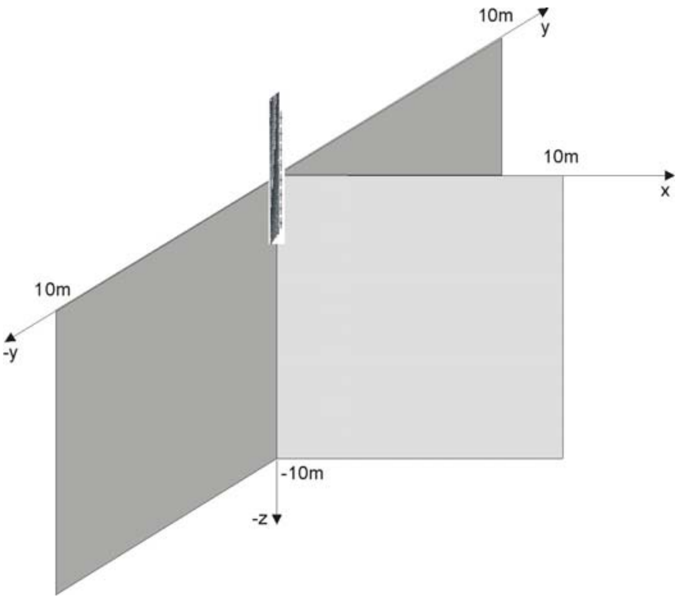

Fig. 9. Coordinate system for near electric field calculation

Such antenna configuration was analyzed using the same method of calculation (NEC2). Configuration consisted of two same antennas, placed parallel and close to each other. Spacing between their axes varied from 1.5λ to 2.0λ (with the 0.25λ step) and produced 0.23 m to 0.39 m spacings between the two antenna housings. One antenna was radiating, while the other served only as the scattering object in the near field. The scattering antenna was modelled with all the dipoles shorted. Near-field values of electric field were computed along the same axes as in the free space analysis.

B. Near-field calculation results

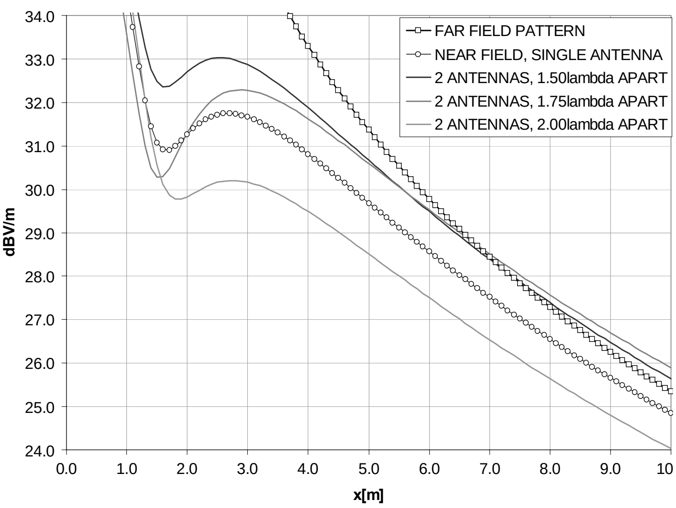

Fig. 10. Calculated electric field in the mainlobe direction, $\varphi = 0º$, $z = 0$ m

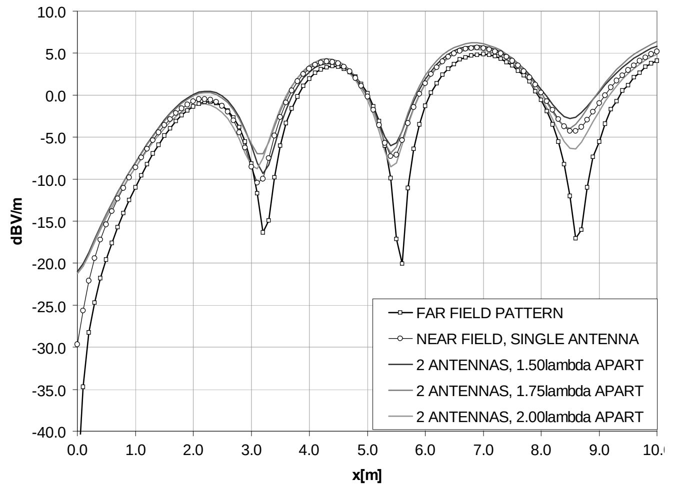

Fig. 11. Calculated electric field, $\varphi = 0º$, z = -5m

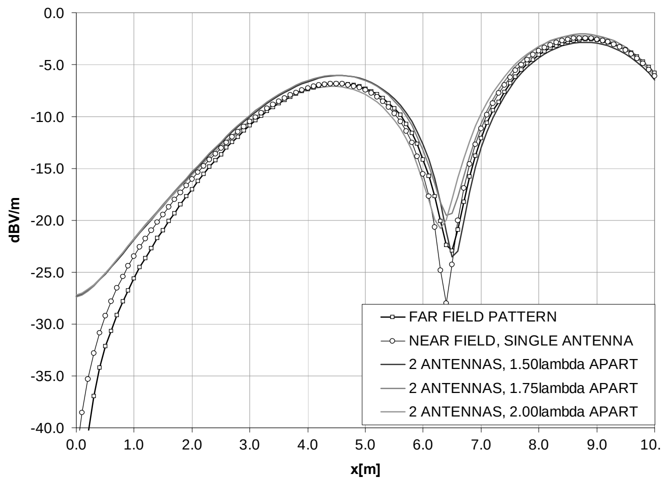

Fig. 12. Calculated electric field, $\varphi = 0º$, z = -10m

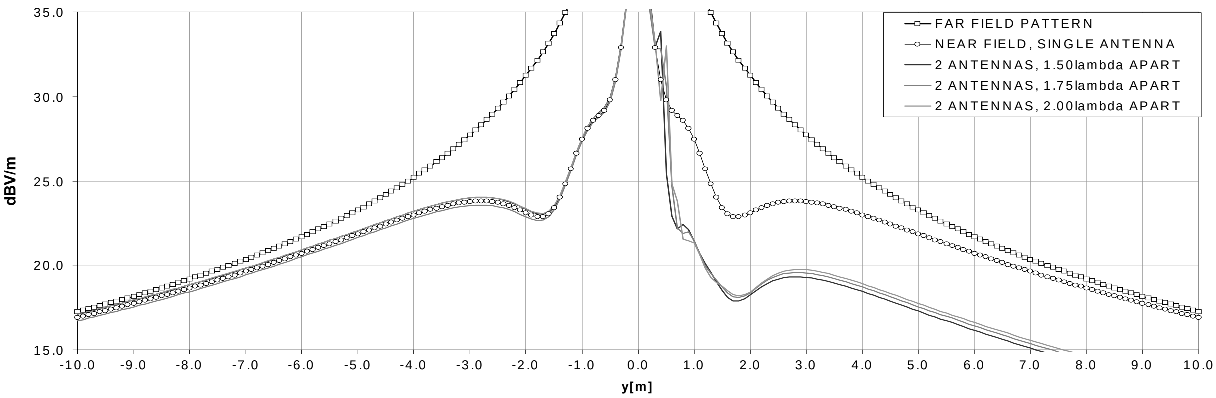

Fig. 13. Calculated electric field, φ = -90º, +90º, z = 0 m

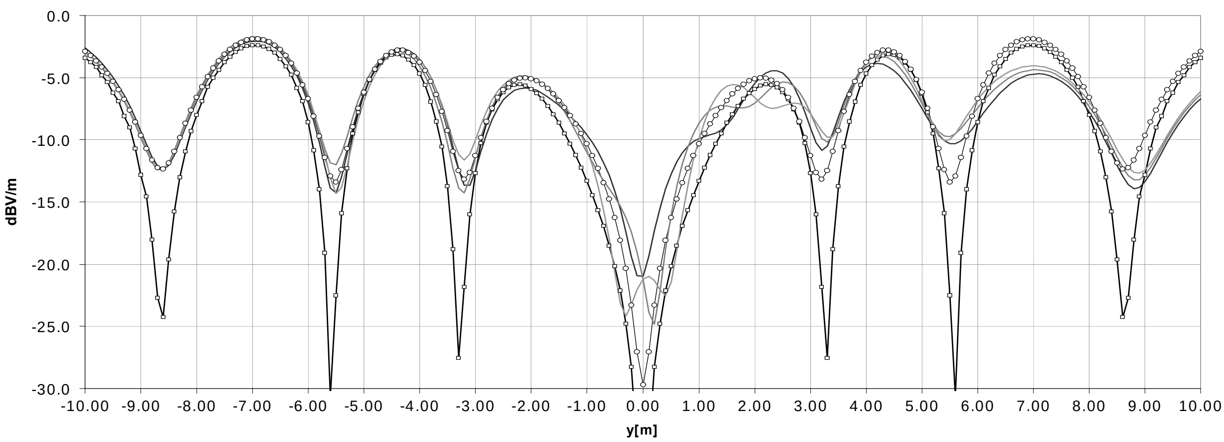

Fig. 14. Calculated electric field, φ = -90º, +90º, z = -5 m (legend from Fig. 13. applies)

The near-fields comparison shown in figures Fig.10. to Fig.15. yields a few important conclusions:

1. When using far-field radiation pattern for near-field calculations, overestimation only happens in the immediate vicinity of the antenna, and only in the mainlobe. For all other directions, near-field amplitudes can be even higher than the values predicted using far-field pattern. This underestimation is significant (cca. 2 dB) in all directions, but it is most noticeable in the nulls of the radiation pattern where it can reach 10-15 dB.

2. Situation gets even worse for the antenna that is accompanied by the second antenna in the immediate vicinity – like in widely used GSM base station configuration (Fig.1.). Near-fields in this case exceed the values predicted using far-field pattern, even in the main lobe of the antenna radiation pattern.

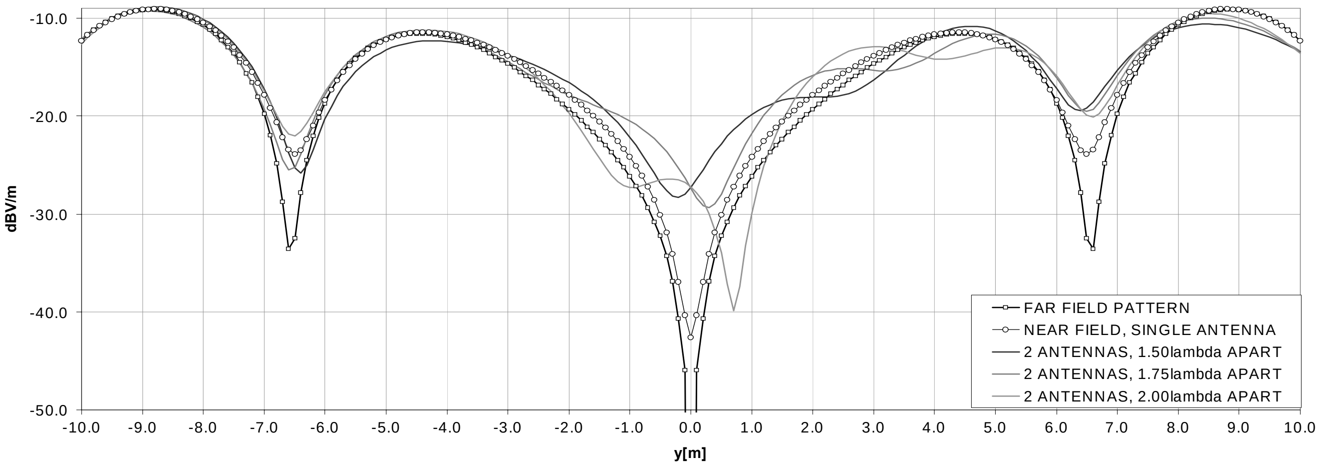

Fig. 15. Calculated electric field, φ = -90º, +90º, z = -10 m

IV. CONCLUSIONS

When calculating field levels around a base station, an engineer often relies on the radiation pattern provided by the manufacturer. This paper shows that this is not always acceptable. Only if the installation is "clean", with no obstacles in the vicinity of the antenna, the factory pattern can be applied. On the other hand, if there are objects nearby the antenna, one must take into account the distortion of the radiation pattern. This distortion, if not calculated accurately, must be regarded as **installation uncertainty** of the antenna pattern. This means that the gain value used for coverage planning or radiation hazard analysis must be regarded as variable. The gain deviates by few dB from the factory value, for some typical cases of installation geometries, as shown in this paper.

If complete accuracy of field levels is needed, the true pattern can be calculated using the proper tools and provided that all antenna and installation parameters are known. The method used in this research was numerical calculation by Method of Moments code NEC [8]. Of course, the method must be individually applied to any specific case.

The analyzed antenna configurations are commonly encountered at the installation sites. The conductive objects in the vicinity of the antenna are generally undesirable, while the multiple-antenna configuration is a result of deliberate installation plan. Nevertheless, these situations tend to distort one of the main characteristics of the antenna, its radiation pattern. When estimating the field amplitude for coverage or some other purpose, one should account for this "installation uncertainty", reaching a few dB of deviation throughout the main lobe. This effect could even be deliberately employed to gain or loose a few dB in wanted direction.

Since it would be impossible to accurately analyze every possible situation, some guidelines should be adopted for EM near-field estimation, e.g. for the described antenna configuration:

- Nulls can be disregarded in the near-field estimation.
- For the worst-case calculation, a protective envelope should be used instead of the radiation pattern. This envelope can be formed by the mainlobe line, combined with the line connecting all the sidelobe peaks for all directions outside the mainlobe, with a 2 dB expansion in all directions.

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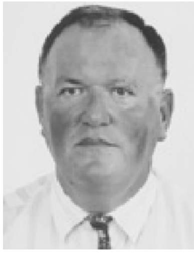

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