A NEW ANTENNA CALIBRATION METHOD AND A SELECTION OF A MEASUREMENT PROBE WITH MINIMAL DISTURBANCE AND SUFFICIENT SENSITIVITY FOR ELECTROMAGNETIC EXPOSURE MEASUREMENTS AROUND WIRELESS BASE STATIONS

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ABSTRACT

To measure electromagnetic fields accurately, the calibration of field probes is necessary. In this paper, an accurate low-cost calibration method is presented. However, calibration does not take into account all influencing factors, especially when measuring fields close to the source (e.g., antenna). While measuring, the electromagnetic field will be disturbed by the measurement probes themselves. So instead of measuring the true free-space field, the disturbed field will be measured. This paper will show that when the disturbance must be limited to a predefined value (e.g., 5 %), a suitable measurement probe with maximum sensitivity can be selected.

INTRODUCTION

To check whether the exposure (public and occupational) of a base station satisfies the guidelines for electromagnetic exposure, electromagnetic field measurements around base stations must be accurate. To perform electromagnetic measurements, calibration of the measurement probes is needed [1], [2]. Therefore, an accurate low-cost calibration method is developed. Due to the non-negligible dimensions of the measurement probes [3], the electromagnetic field probes will disturb the field that has to be measured. In principle, the calibration should take into account the disturbance of the probe. However, this is only true if the disturbance is equal in the calibration set-up and during the measurement. This is certainly not the case if the measurement is done in the near field of a base station because calibration is mostly done measuring far fields of one or more electromagnetic sources. It is shown that when a maximal disturbance of e.g. 5% is required, different probes for near- and far-field measurements respectively must be selected.

CALIBRATION

Antenna calibration involves the determination of the antenna factor. The antenna factor is defined as the ratio of the strength of the field in which the antenna is immersed and the output voltage across the load connected to the antenna:

$$AF = 20 \cdot \log\left(\frac{E^i}{V^{meas}}\right) \text{ [dB(1/m)]} \qquad (1)$$

E^i is in this equation the electric field incident on the antenna to be calibrated and V^{meas} is the voltage measured at the terminals of the antenna to be calibrated. It is assured that for the calibration the far-field conditions are fulfilled.
The developed method is based on the three-antenna method [1], [2]. The three antennas to be calibrated are used as transmitting-receiving pairs. The three antenna factors are derived from three equations obtained after three transmission measurements. To determine the antenna factor accurately, measurements are mostly done in an anechoic chamber which is very expensive. Therefore, a low-cost method is needed. With our method the antenna calibration needs not be performed in an anechoic chamber: the calibration is done in an indoor open-site surrounded by absorbers

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to minimize interference. In order to account for the non-anechoic property of the measurement site, the method must eliminate residual reflections because the equations assume that only the direct beam is present. Therefore we perform a de-embedding step. We have developed two methods to de-embed the reflected beam: in the first method an additional measurement with an absorber in between the two antennas is needed. The second method uses the inverse FFT to obtain the time-domain signals and time-domain gating to eliminate the residual reflection: the latest arriving time-components – the reflected beam will arrive later than the direct beam – are filtered. Finally, we take the FFT to obtain the corrected transmission results in the frequency domain. The results obtained with our method are comparable with those obtained in an anechoic chamber. To check the accuracy we compare the antenna factor of a conical dipole antenna obtained with our method with the antenna factor obtained in an anechoic chamber in the Austrian Research Center of Seibersdorf. The antenna factor is determined in the frequency range 600 - 2000 MHz. Fig. 1. shows the result for the de-embedding by taking the inverse FFT.

The de-embedding method using an absorber between the two antennas gives already good results: the maximum deviation is 1.30 dB and the average deviation is 0.41 dB. Using the inverse FFT gives the best results with a maximum deviation of only 0.84 dB (Fig. 1.). The average deviation is only 0.39 dB. The Austrian Research Center Seibersdorf specified the antenna factor with an uncertainty of ± 1 dB. So the results are lying within this uncertainty interval for all frequency points when the inverse FFT-method is used.

SELECTION OF A SUITABLE MEASUREMENT PROBE

The characterization of the influence of the measurement probe on the evaluation of the far and near field of an electromagnetic source was performed using a numerical electromagnetic computational program (NEC-Win-Pro$^{©}$). First, the calibration method was simulated and the antenna factor of the measurement probe is calculated. Secondly, the measurement configuration is simulated. Three orthogonal components of the electric field are “measured”. The relative disturbance of the measurement probe is determined as the relative difference between the measured field and the true field. For the simulation of the free-space measurements a 900 MHz Kathrein GSM 736863 base station is used. The far-field distance for this antenna is 22.4 m. The measurements are simulated for a frequency of 900 MHz.

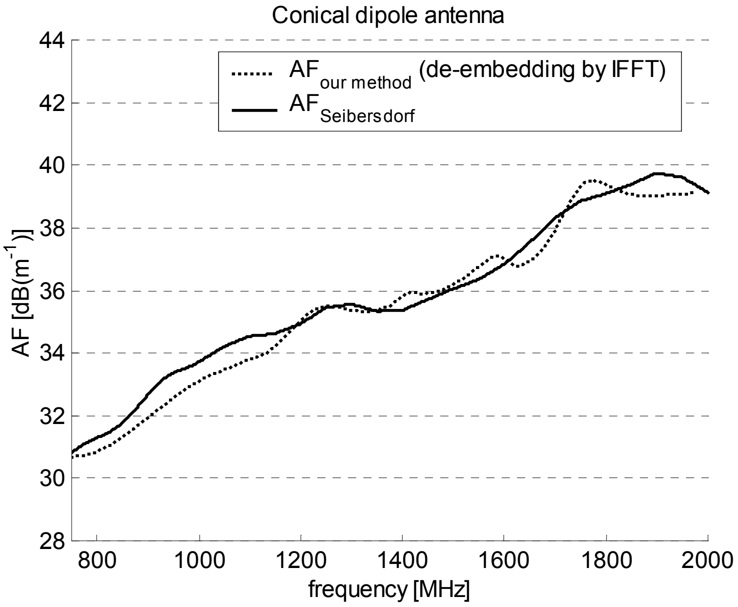
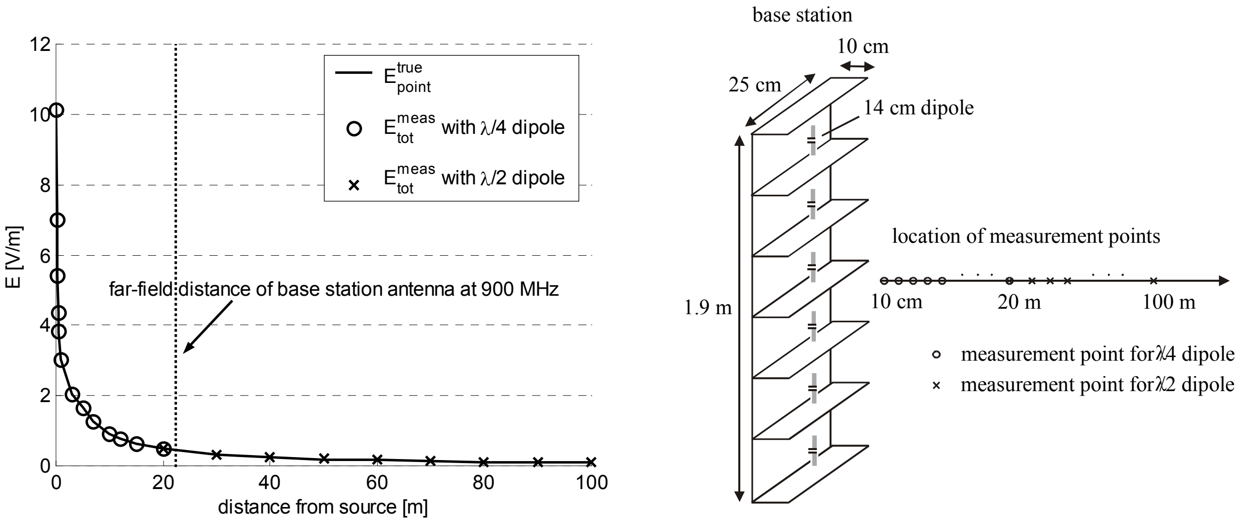


Fig. 1. Comparison of the antenna factors of the conical dipole antenna respectively obtained by the Austrian Research Center in Seibersdorf and obtained with our method with de-embedding by using the inverse FFT.

A disturbance below 5% is desired**.** For electric far-field measurements, a dipole with length λ/2 (15 cm, with λ the wavelength) and a radius of the thickness of 1.8 mm will satisfy this requirement. The used λ/2 dipole is very sensitive, with an antenna factor of 27 dB(1/m) at 900 MHz. High sensitivity is required for far-field measurements, due to the low field values.

But for near-field measurements this probe will have a disturbance of more than 5% due to its large dimensions. This can be solved by using a smaller probe, that has a better spatial resolution which is necessary due to fast changing field values in the near field. On the other hand the probe will be less sensitive. In order to obtain a disturbance below 5% but still have the highest sensitivity, a design of the dimension of the probe has to be made using simulations. This resulted in a 7.5 cm probe, corresponding with λ/4 at 900 MHz. The thickness is identical to the one of the λ/2 probe. The antenna factor is 44 dB(1/m) at 900 MHz, higher than the one of the λ/2 dipole but low enough to measure the higher values in the near field. The results for simulations of measurements from 10 cm to 100 m from the base station are excellent: the disturbance is below 1%. The maximum disturbance for the λ/4 dipole (used for near-field measurements) and the λ/2 dipole (used for far-field measurements) is respectively 0.68% and 0.54%. Fig. 2. shows the results.

For occupational exposure it is necessary to perform measurements close to the base station. Therefore, simulations of field measurements from 4 cm to 20 cm in steps of 1 cm are performed with both the λ/4 dipole and the λ/2 dipole. Fig. 3. shows the measured and the true electric field. The disturbance of the λ/4 dipole is below 5 % (maximum 3.3 % at 4 cm) as desired while the λ/2 dipole produces disturbances of more than 40 %. This procedure permits to select the probes with minimal disturbance and sufficient sensitivity.



(a)

(b)

Fig. 2. The true electric field at 900 MHz of the GSM base station versus the electric field measured with the λ/4 and λ/2 dipoles as a function of the distance and (b) the base station and the location of the measurement points.

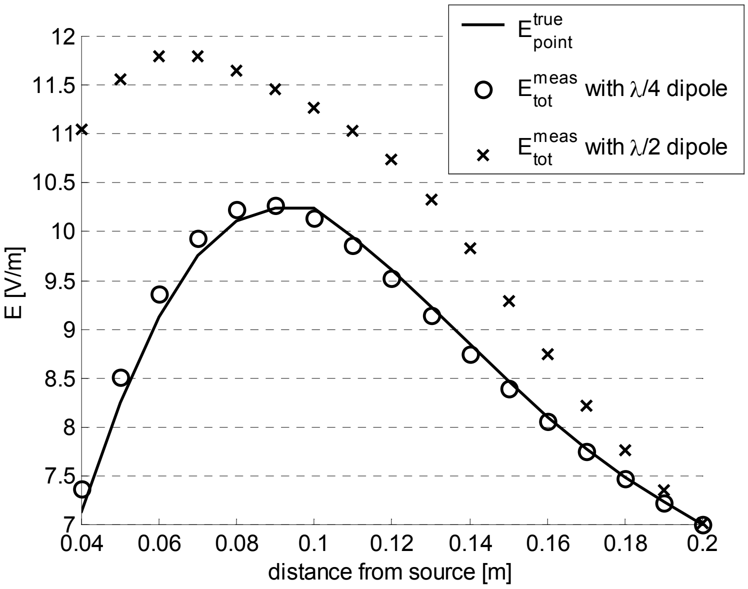


Fig. 3. The true electric field versus the field measured with the λ/4 and λ/2 dipole from 4 cm to 20 cm from the GSM base station.

CONCLUSIONS

We have presented an improved method to determine the antenna factor. From the results shown in this paper, we can conclude that our calibration method is accurate and consistent. Furthermore, the calibration is easy to perform with a network analyzer and this method does not need to be performed in an anechoic chamber to be accurate resulting in a low-cost method.

Next, a selection of measurement probes with a disturbance required to be lower than 5 % for near- and far-field exposure measurements around a 900 MHz GSM base station is made. The design of the probes has been done using simulations of measurements. It was concluded that for far- and near-field measurements different probes have to be used. For measurements in the far field of the base station, a λ/2 dipole offers the highest sensitivity and a disturbance lower than 1 %. The length of the near-field dipole resulted in 7.5 cm corresponding to λ/4 at 900 MHz taking into account the required disturbance of lower than 5 % and the highest reachable sensitivity under this condition.

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