Assessment of measurement uncertainty for verification of compliance with guidelines for human exposure to EMFs from AM broadcasting transmitters

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Abstract: In this paper we analyze the uncertainty in measurement when assessing the exposure levels of the general public to RF electromagnetic fields (EMFs) from AM broadcasting transmitters. The purpose of measurement was to evaluate whether human exposure levels are in compliance (or not) with protection guidelines. Six sources of uncertainty were selected, and in order to allow for the propagation characteristics of the middle frequency range, the uncertainties of both the electric and magnetic fields were evaluated. Estimated uncertainties were identical to ±2.34 dB.

Keywords: uncertainty, Am broadcasting transmitter, electromagnetic fields (EMFs), human exposure level

Classification: Electromagnetic Compatibility (EMC)

References

1 Introduction

The middle frequency (MF) band (0.3∼3 MHz), including AM broadcasting signals, has different propagation features compared with those of the ultra-high-frequency (UHF) band (0.3∼3 GHz) which includes the signal range radiated from mobile base stations and also from television broadcasting transmitters in many countries. For the general public, the field region around mobile base stations is regarded as radiating far-field, but AM transmitters is as reactive, or reactive-radiating near-field owing to the relatively long wavelengths of the MF-band. So, for AM transmitters the uncertainties in measurement of both the electric and magnetic field strengths should be estimated and a method of estimating and expressing uncertainty when evaluating the levels of human exposure to EMFs from mobile base stations has been proposed [1, 2].

The sources of uncertainty are classified into two groups based on their method of evaluation. Type A sources of uncertainty were selected to include the power drift, body influence, mismatch with transmitting antenna, and spatial averaging, whereas Type B sources were selected to include calibration, isotropy and linearity of receiving probe and power chain.

2 Evaluation of Type A standard uncertainty

The in situ measurement procedure used to estimate each of the standard uncertainties of Type A followed the Korean standard [3]. In our measurement, we used the NARDA EHP-200A as the main receiver.

2.1 Power drift

In order to obtain the uncertainty value of power drift, thirty repeated measurements were performed around twenty AM transmitters. At each measurement position, we assumed the spatial average of the electric and magnetic field strengths at three heights (1.1 m, 1.5 m, and 1.7 m) with root-mean-square mode over one or six min [3, 4, 5]. After completing the measurements, the arithmetic means of each averaged value for the electric and magnetic fields, and then the standard deviations, were calculated by (1) and (2), respectively.

$$\bar{q} = \frac{1}{N} \sum_{k=1}^{N} q_k$$

$$s(q_k) = \frac{1}{\sqrt{N-1}} \sqrt{\frac{1}{N} \sum_{k=1}^{N} (q_k - \bar{q})^2}$$
where N is 30 and \( q_k \) is the spatially averaged field values of electric or magnetic field strength obtained from 30 repeated measurements. The calculated standard deviations of the power drift were in a range from 0.02 dB to 0.82 dB for the electric field, and 0.04 dB to 0.80 for the magnetic field for twenty transmitters as shown in Fig. 1.

Letting the probability function for the standard uncertainty of power drift by student-\( t \) distribution [6] and assuming the two-sided confidence level of 95%, we can get the \( t \)-factor: \( t_r = t_{0.05} = 2.05 \) (degree of freedom (DoF) = 29). Using these confidence level parameters, DoF, and \( t \)-factor, we obtain the standard uncertainty of power drift as

\[
 u_{pd} = t_r \times \frac{s(q_k)}{\sqrt{N}} 
\]  

(3)

![Fig. 1. Deviations and standard uncertainties caused by power drift. (a) For electric field. (b) For magnetic field. Experimental data were obtained from thirty repeated measurements around AM broadcasting transmitters.](image)

### 2.2 Body influence

In order to estimate the effect of a nearby human body, which should be kept some distance away from the receiver, we considered the differences in the spatial average electric and magnetic field strengths, when an experimenter was 1.0 m, 2.0 m, or 3.0 m from the probe around 20 AM transmitters.

With 95% confidence level and probability function of student \( t \)-distribution (DoF = 19), we got \( t_r = 2.09 \). Thus, the standard uncertainty for each case of distance differences can be calculated by (1). In applied equation \( q_k \) denotes the differences between spatially averaged field values electric or magnetic field strength of 1.0 m and 2.0 m apart from probe, 1.0 m and 3.0 m, and 2.0 m and 3.0 m of each transmitter, respectively.

The ranges of standard uncertainties were from 0.03 dB to 0.04 dB for both the electric and magnetic fields. Therefore, we estimate the standard uncertainty of the influence of a nearby body to be 0.04 dB.
2.3 Noise
This source of uncertainty elates to the amount of signal strength when the AM transmitter is off. These kinds of sources are well defined. However, measurement in the off state was impossible in our in situ measurement, so, the standard uncertainty of noise was neglected as in zero [2].

2.4 Mismatch in receiving probe and AM transmitter’s antenna
As mentioned in [2], this source of uncertainty reflects the directional mismatch between transmitting and receiving antennas. However, the configuration of the AM transmitter antenna is a monopole type with horizontally isotropic characteristics, so this type of uncertainty can be negligible under the condition of line-of-sight (LOS).

2.5 Spatial averaging
As explained in detail in [2] for UHF frequencies, the transmitted EMFs are affected by spatial variations known as small-scale fading due to multipath propagation, and an appropriate correlation distance between adjacent measurement points has been proposed [7]; however, such a distance in the MF-band is very long, so it is very difficult to apply it for AM broadcasting signals. Conceptually, the greater number of points we selected, the more exact exposure level we could get. For this reason we selected 10 cm as the appropriate distance since the size of the probe was 10 cm. The number of measurement points was either three or nine. We measured and compared the spatially averaged values of thirty-five, nine, and three points around the twenty target transmitters.

For the 35 points, there were 5 points at each height (i.e., 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, and 1.7 m). For nine points, the three points at each height. Three points were located at the center of each of the heights (1.1 m, 1.5 m, 1.7 m).

The distribution of the difference of the spatially averaged values between the different numbers of points for twenty transmitters are in a range from 0.01 dB to 0.61 dB in electric field and 0.01 dB to 0.93 dB in magnetic field strengths. Applying the confidence level of 95% and assuming that the probability function has the form of the student-\( t \) distribution (DoF = 19, this is equal to the number of transmitters) with \( t_c = 2.09 \). Thus we can write the expression for the standard uncertainty by (1). In applied equation \( q_k \) is the difference between the spatially averaged field values of thirty-five, nine, and three points of each transmitter. The standard uncertainty for spatial averaging of the AM broadcasting signal was estimated to be 0.07 dB and 0.09 dB for the electric and magnetic fields, respectively.

3 Evaluation of Type B standard uncertainty
Evaluation of Type B sources of uncertainty is obtained from reliable information such as calibration sheets [8].
4 Evaluation of combined and expanded uncertainty

The combined uncertainty value is same as root-sum-square of those of all standard uncertainty sources \((u_k)\) as shown in (4). In our calculation all of the individual standard uncertainty sources are considered to be uncorrelated \((c_k = 1.0)\). The calculated combined uncertainty is 1.19 dB in electric field and 1.20 dB in magnetic field.

\[
u_c = \sqrt{\sum_{k=1}^{N} c_k^2 u_k^2}
\] (4)

4.1 Expanded uncertainty

The expanded uncertainty or overall uncertainty is the final form of uncertainty which is calculated with the combined uncertainty and coverage factor \((k)\).

\[
U = k \times u_c
\] (5)

In addition, expanded uncertainty is the kind of uncertainty, which also has DoF. The effective degree of freedom (eDoF) of expanded uncertainty can be calculated by the Welch-Satterthwaite equation \([1]\). The calculated values for the electric and magnetic fields were 6,929 and 6,897, respectively.

The value of \(t_{0.025}\) for one-sided confidence level of 95% and eDoF = 6,929 and 6,897 is nearly equal to 1.96. Thus we selected 1.96 as the coverage factor. Therefore, the expanded uncertainty was estimated to be 2.34 dB. Table I summarizes all of the individual standard uncertainties, combined uncertainty, and expanded uncertainty.

![Table I. Uncertainty budget for evaluation of human exposure level from AM transmitter](image)

5 Conclusion

In this paper, we proposed a method and procedure to estimate the measurement uncertainty for evaluating human exposure levels to EMFs from AM broadcasting.
transmitters. Compared with UHF frequency signals, the MF band (includes AM broadcasting) signals have different propagation characteristic. So, in order to estimate the uncertainty both the electric and magnetic field strengths should be considered.

Compared with the measurement uncertainty of the RF-EMFs radiated from a mobile base station, that of AM broadcasting transmitter is relatively small. The AM transmitter transmits stable signals, in contrast to mobile base stations, which are subject to fluctuation by traffic. The expanded uncertainty of AM broadcasting transmitter was determined to be $\pm2.34\, \text{dB}$ for both the electric and magnetic field strengths.

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