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SERIES K: PROTECTION AGAINST INTERFERENCE

ITU-T K.91 – Supplement on radiofrequency exposure evaluation around underground base stations

ITU-T K-series Recommendations – Supplement 20

Supplement 20 to ITU-T K-series Recommendations

ITU-T K.91 – Supplement on radiofrequency exposure evaluation around underground base stations

Summary

Supplement 20 to ITU-T K-series Recommendations contains the measurement and full-wave computation results of radio frequency exposure from underground base stations (BSs), to evaluate the exposure from them.

Measurement and computation methods of human exposure to electromagnetic fields (EMFs) from fixed radio sources like mobile BSs have been standardized and published as ITU-T K-series Recommendations and IEC 62232. These also include methods prescribed in Japanese regulations and have been basically assumed to be applied to radio sources installed above ground.

Underground BSs for use in small cells of fourth generation (4G) mobile networks are installed underground to construct service areas above ground and also expected to be used for fifth generation (5G) mobile networks.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T K Suppl. 20	2020-05-20	5	11.1002/1000/14317
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Keywords

RF exposure evaluation, underground base station.

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Supplement 20 to ITU-T K-series Recommendations

ITU-T K.91 – Supplement on radio frequency exposure evaluation around underground base stations

1 Scope

This Supplement contains the measurement and full-wave computation results of radio frequency (RF) exposure from underground base stations (BSs) using the measurement and full-wave computation methods introduced in [ITU-T K.91], to evaluate the exposure from them.

2 References

[ITU-T K.52] Recommendation ITU-T K.52 (2021), *Guidance on complying with limits for human exposure to electromagnetic fields*.

[ITU-T K.61] Recommendation ITU-T K.61 (2018), *Guidance on measurement and numerical prediction of electromagnetic fields for compliance with human exposure limits for telecommunication installations*.

[ITU-T K.70] Recommendation ITU-T K.70 (2020), *Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations*.

[ITU-T K.83] Recommendation ITU-T K.83 (2022), *Monitoring of electromagnetic field levels*.

[ITU-T K.91] Recommendation ITU-T K.91 (2022), *Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields*.

[ITU-T K.100] Recommendation ITU-T K.100 (2021), *Measurement of radio frequency electromagnetic fields to determine compliance with human exposure limits when a base station is put into service*.

[IEC 62232] IEC 62232:2017, *Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure*.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 antenna [ITU-T K.70].

3.1.2 base station (BS) [ITU-T K.100].

3.1.3 electric field strength (*E*) [ITU-T K.83].

3.1.4 electromagnetic field (EMF) [ITU-T K.91].

3.1.5 equivalent isotropically radiated power (EIRP) [ITU-T K.52].

3.1.6 exposure [ITU-T K.52].

3.1.7 exposure level [ITU-T K.52].

3.1.8 power density (*S*) [ITU-T K.52].

3.1.9 radio frequency (RF) [ITU-T K.70].

3.1.10 reference levels [ITU-T K.70].

3.2 Terms defined in this Supplement

None.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

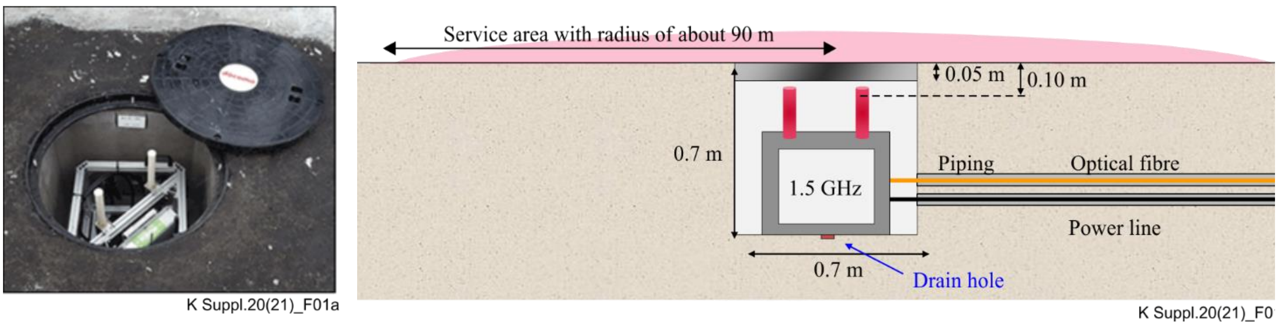
4G	Fourth Generation
5G	Fifth Generation
EIRP	Equivalent Isotropically Radiated Power
EMF	Electromagnetic Field
FDD	Frequency Division Duplex
FDTD	Finite-Difference Time Domain
FR1	Frequency Range 1
LTE	Long-Term Evolution
MIMO	Multiple Input Multiple Output
NR	New Radio
RF	Radio Frequency
SISO	Single Input Single Output
TDD	Time Division Duplex

5 Conventions

None.

6 Overview of underground base station

Underground BSs are used in small cells of fourth generation (4G) mobile networks and are also expected to be used similarly in the fifth generation (5G) setting. They have been developed to secure communication areas mainly in locations where there are no suitable places for installation of antennas, such as tourist and scenic spots. An overview of their structure and service area is shown in Figure 1. The assumed main specifications are given in Table 1.



a b

Figure 1 – Overview of structure and service area of underground base stations: a – photo; b – structure and service area

Table 1 – Assumed main specifications of underground base stations

Item	Value
Wireless access system	Frequency division duplex-long-term evolution (FDD-LTE), time division duplex-long-term evolution (TDD-LTE), 5G new radio (NR) frequency range 1 (FR1)
Frequency	700 MHz – 4.6 GHz
Frequency bandwidth	15 MHz, 20 MHz, 100 MHz
Multiple input multiple output (MIMO)	2 branches or more

7 Evaluation points and spatial averaging

The spatial averaging methods specified in [IEC 62232] and [ITU-T K.61], introduced in [ITU-T K.91], have been used for whole-body human exposure evaluation because an underground BS forms non-uniform field distributions. The 20-point method has been used among several spatial averaging methods because the same spatial averaging method is stipulated by national regulations in Japan for the compliance assessment of EMF human exposure to mobile BSs [b-MIC].

All points to be evaluated are shown in Figure 2. The evaluation points in the horizontal direction are specified in [b-MIC], and the points in the vertical direction for spatial averaging are specified in [IEC 62232], [ITU-T K.61] and [b-MIC].

The evaluation points in the horizontal direction are specified radially at steps of less than the wavelength divided by 10 (approximately 20 mm at 1.5 GHz) around the wave source as shown in Figure 2-b. The evaluation points in the vertical direction at a certain horizontal evaluation point are defined from height 0.1 m to 2.0 m at intervals of 0.1 m or less (when the frequency is 300 MHz or higher) assuming the space occupied by a human body is as shown in Figure 2-c.

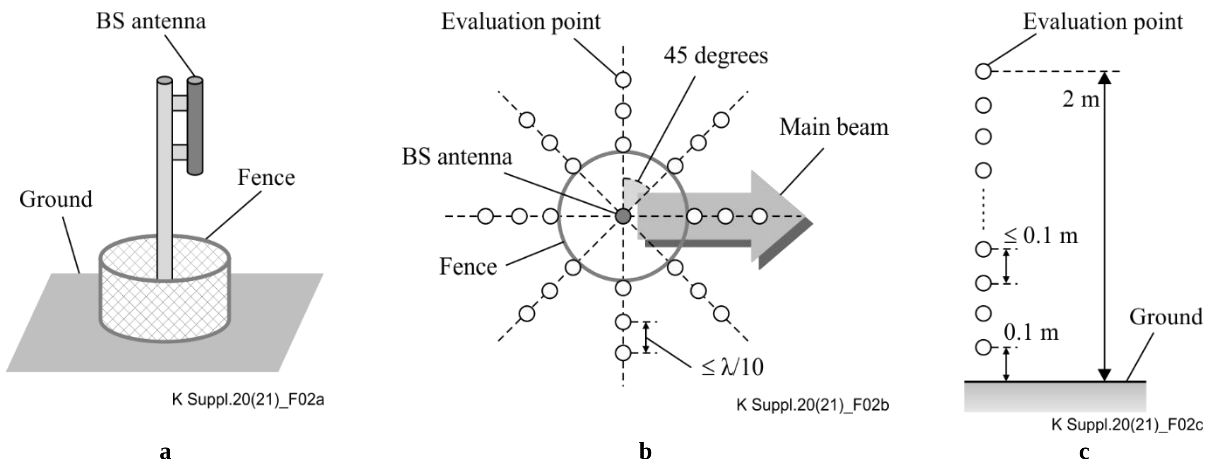


Figure 2 – All evaluation points for spatial averaging: a – base station example; b – top view; c – side view

8 Reference levels

Reference levels for compliance assessment defined in [b-MIC] were used because these levels are almost the same as those given in [b-ICNIRP] introduced in [ITU-T K.91]. The reference levels are regulated by a value averaged over 6 min of the electric field strength, the magnetic field strength and power density (when the frequency is 300 MHz or higher). The reference levels in the 1.5 GHz band in [b-MIC] are 10 W/m^2 for spatial averaging and 20 W/m^2 for the spatial peak.

9 Evaluation example of frequency selective measurement

9.1 Purpose

The purpose of this evaluation is to confirm that the EMF field strengths around the underground BS are below the reference levels using frequency selective *in-situ* measurement.

9.2 Target base station

The main specifications of the target BS are given in Table 2.

Table 2 – Main specifications of the target base station

Item	Value
Wireless access system	FDD-LTE
Frequency	1.5 GHz band (band 21)
Frequency bandwidth	15 MHz
MIMO	2×2

9.3 Methods

Frequency selective measurement methods specified in [IEC 62232] and introduced in [ITU-T K.91] were used for more accurate exposure evaluation. In this case, since there were no other BSs in the vicinity using the same frequency, it was possible to obtain the power densities of only the underground BS.

Furthermore, for the FDD-LTE BS, the power densities equivalent to the maximum traffic were measured using a spectrum analyser by the method given in [IEC 62232]. In the method, the power densities of the resource blocks that regularly become the peak power are measured with zero span frequency under the condition that the resolution bandwidth is 1 MHz and the time resolution coincides with 1 symbol (about 71 μs) of the FDD-LTE signal. The measurement value obtained is extrapolated by the ratio of the number of resource blocks corresponding to the employed bandwidth to the number of measured resource blocks.

The SRM-3006 (Narda) analyser, which has isotropic sensitivity and frequency selectivity, was used for measurement. However, the minimum time resolution that can be set in the isotropic axis mode of this equipment is greater than 1 symbol. Therefore, the detector and the trace were set to maximum so that they are not underestimated. The set parameters of the measuring equipment for this evaluation are given in Table 3.

Table 3 – Set parameters of SRM-3006 for this evaluation

Item	Value
Axis	Isotropic
Resolution bandwidth	1 MHz
Video bandwidth	100 kHz
Result (Detector)	Maximum
Trace	Maximum

Since there is an excessive number of evaluation points in the horizontal direction for measurement, in order to reduce the measurement time and obtain conservative evaluation results, the sensor scanned slowly in the horizontal direction in the range of 3 m around the BS, maintaining a constant height while repeatedly sweeping with the maximum trace, as shown in Figure 3. The maximum value in the horizontal direction was measured at each evaluation point in the vertical direction. Furthermore, the maximum value was obtained in all horizontal directions at each height, and the maximum and the averaged values of those in the vertical direction were calculated.

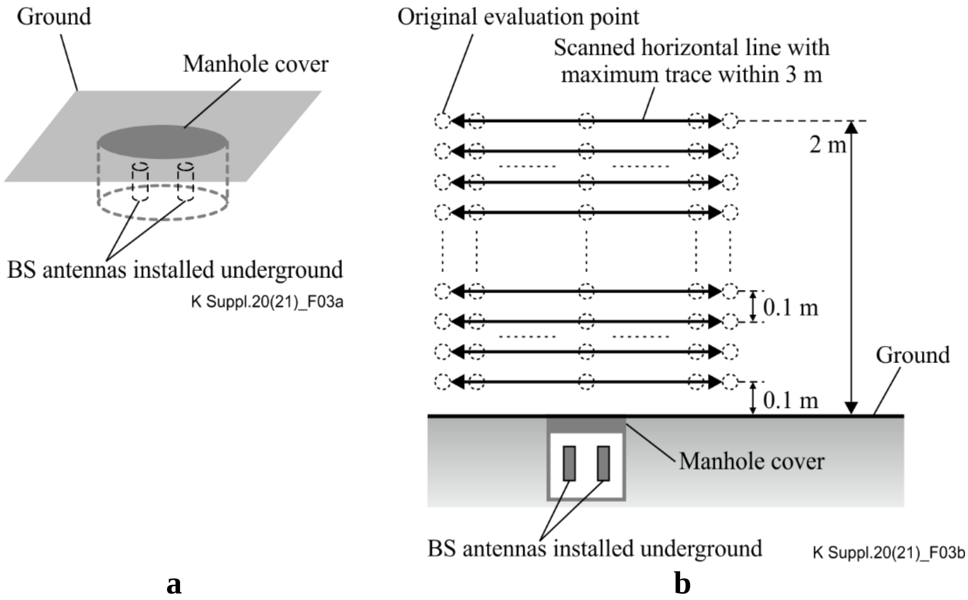


Figure 3 – Scanned horizontal lines with maximum trace to reduce measurement time and obtain conservative evaluation results: a – underground base station; b – side view

9.4 Results

The vertical direction dependence of the maximum power density in all horizontal directions at each height normalized by the EIRP of 1 W per MIMO branch is shown in Figure 4. The maximum value and the averaged value of those in the vertical direction are 1.9 W/m^2 and 0.27 W/m^2, respectively. These values are lower than both the spatial maximum reference level and the spatial average reference level regulated by [b-MIC].

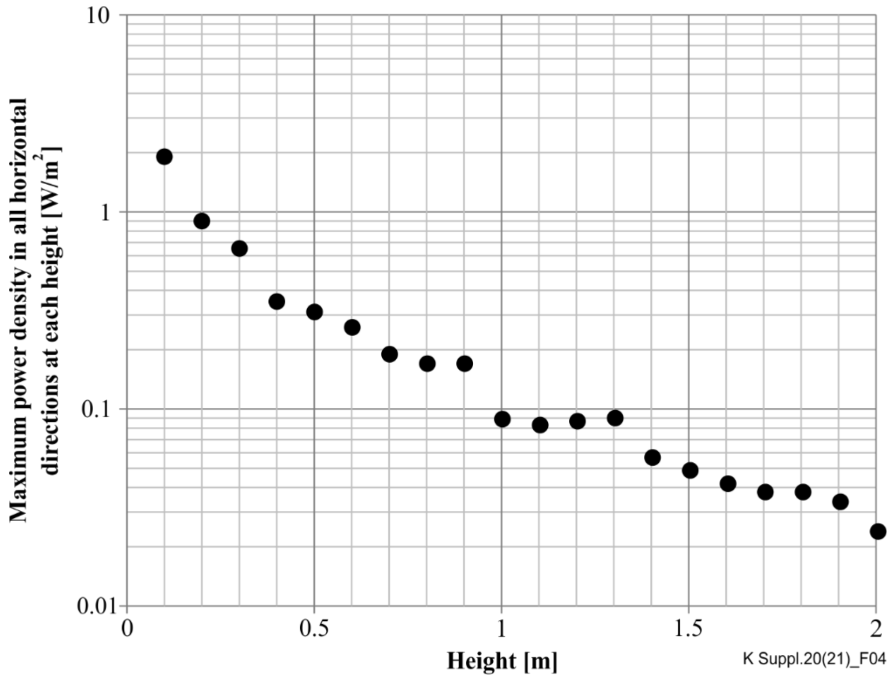


Figure 4 – Vertical direction dependence of the maximum power density in all horizontal directions at each height normalized with EIRP 1 W per MIMO branch

10 Evaluation example of full-wave computation

10.1 Purpose

The purpose of this evaluation is to investigate the characteristics of the EMF distributions from underground BSs. The first characteristic is the relationship between height and electric field strength, which is used to derive an appropriate height range for a spatial averaging scheme based on the 20-point method. The second characteristic is how much higher the electric field strengths are when an antenna is installed in free space, which is used to derive an appropriate correction coefficient for spherical formulas estimating electric field strength.

This evaluation was carried out by the Information and Communication Council of the Ministry of Internal Affairs and Communications of Japan [b-ICC].

10.2 Target base station

The main specifications of the target BS are given in Table 4.

Table 4 – Main specifications of the target base station

Item	Value
Wireless access system	None (Continuous wave)
Frequency	700 MHz band (band 28), 800 MHz band (band 19), 1.5 GHz band (band 21), 1.7 GHz band (band 3), 2 GHz band (band 1), 3.5 GHz band (band 42), 3.7 GHz band (band n77), 4.5 GHz band (band n79)
Frequency bandwidth	None (continuous wave)
MIMO	1×1 (single input single output (SISO))

10.3 Methods

Full-wave computation using the finite-difference time domain (FDTD) method and basic computation using the spherical formula specified in [IEC 62232] and introduced in [ITU-T K.91] were used for this exposure evaluation.

One of the numerical analysis models using FDTD method for underground BSs is shown in Figure 5. The source antenna was of the dipole type and was set vertically or horizontally polarized. The depth of handhole was set to 860 mm or 1 160 mm based on applicable Japanese standards. The combinations of dielectric constants of the structures around the antenna were assumed to be dry to wet as shown in Table 5. The Xfdtd ver. 7.8 was used for the FDTD numerical analysis, and a 7-layer absorbing boundary of the perfectly matched layer was applied.

Figure 6 shows the procedure for investigation of the relationship between height and electric field strength to derive an appropriate height range for spatial averaging scheme.

Figure 7 shows the procedure for investigation of how much higher the electric-field strengths are when an antenna is installed in free space to derive an appropriate correction coefficient for spherical formulas.

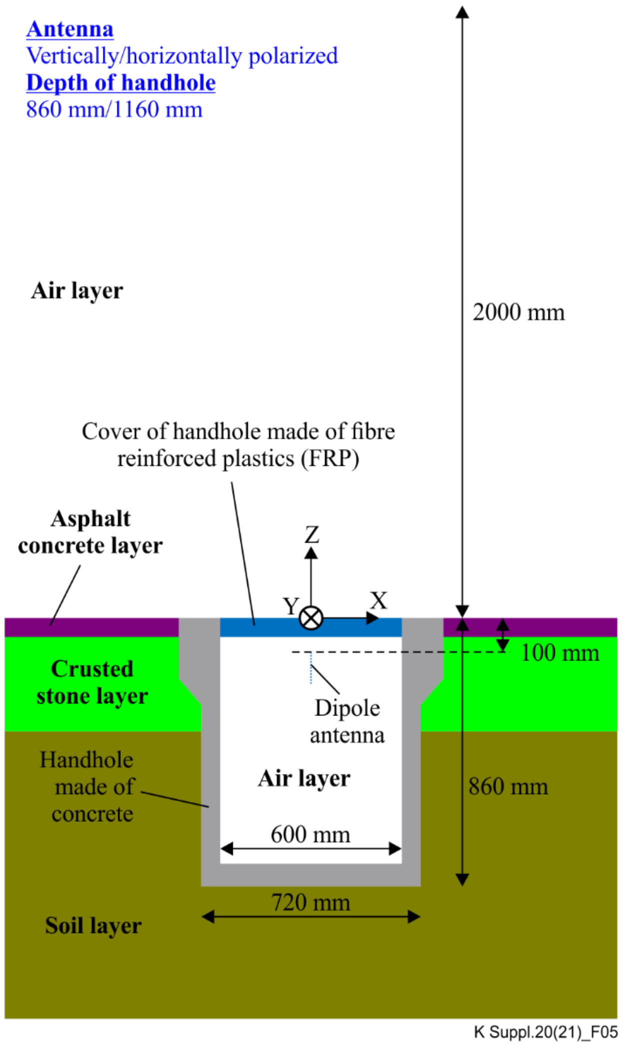


Figure 5 – One of the numerical analysis models for underground base stations

Table 5 – Real part of complex relative permittivity for each material constructing the numerical analysis models

Assumed state	Real part of complex relative permittivity				
	Cover	Handhole	Asphalt concrete	Crushed stone	Soil
Dry	2.6, 4	2, 2.8, 4, 6	5	7	2
Moderate		2, 2.8, 4, 6, 8			5
		6, 8, 12, 20			10
Wet		8, 12, 20			20, 40[a]

[a] For 700 and 800 MHz bands only.

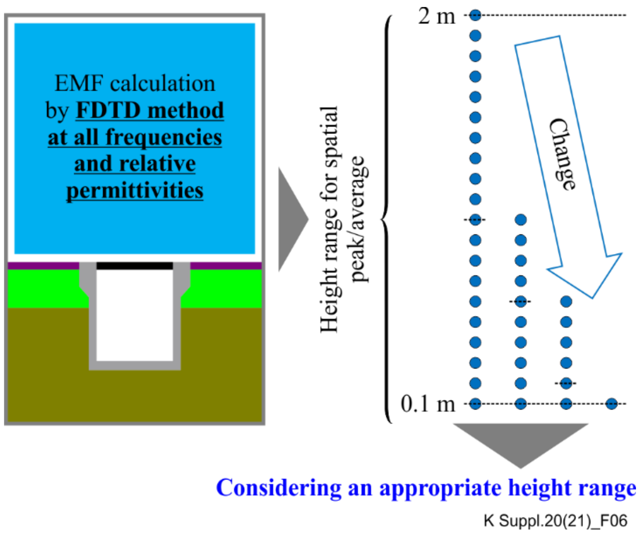


Figure 6 – Procedure for investigation of the relationship between height and electric field strength to derive an appropriate height range for spatial averaging scheme

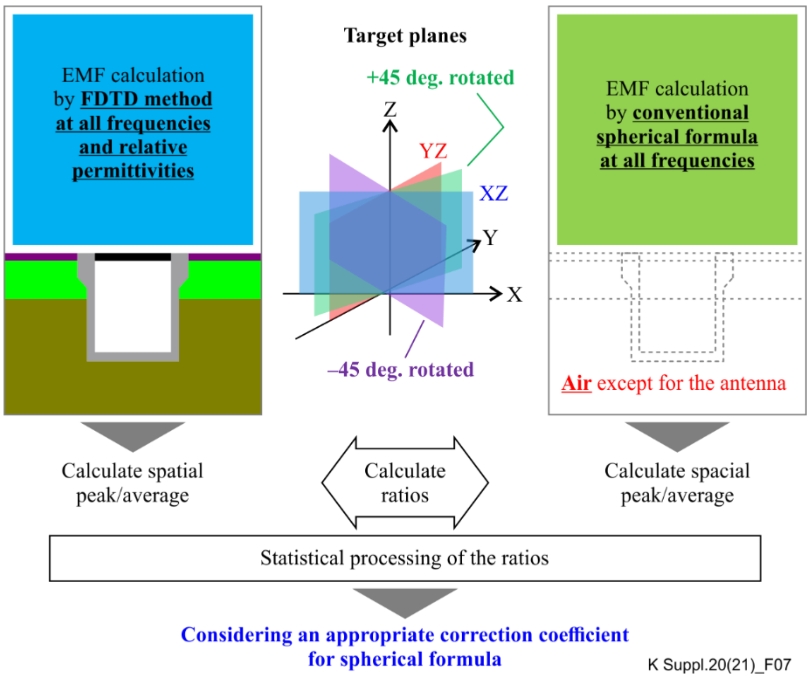


Figure 7 – Procedure for investigation of how much higher electric-field strengths are when an antenna is installed in free space to derive an appropriate correction coefficient for spherical formulas

10.4 Results

An example result of the dependencies of the spatial average and peak exposure levels in the vertical direction on height ranges for a spatial averaging scheme based on the 20-point method at the evaluation point directly above the antenna in the 2 GHz band is shown in Figure 8. Since the shorter the height range, the larger the average value, this indicates that the conventional spatial averaging scheme can underestimate the exposure levels for people with relatively small stature from underground BSs. To confirm, results under other typical evaluated conditions showed a similar tendency.

One possible solution is to apply a shorter height range to the spatial averaging scheme based on the 20-point method. This height range can be, for example, a height range based on the average height of a child aged 1 yearwho is approximately able to walk. This height range is considered adjustable, depending on the circumstances of each country.

Dependency of the maximum value of the ratios of exposure levels by numerical analysis to those by the conventional spherical formula in each condition on the frequency is shown in Figure 9. Each value on the vertical axis is the larger of the maximum value and the 95% value obtained from the samples of the ratios calculated from the EMF numerical analyses at all relative permittivities in Table 5, including estimated extended uncertainty ±0.53 dB in the numerical analyses (k = 2). The maximum value of the ratios in all evaluation conditions was 5.04 by converting 7.02 dB.

In order to ensure conservative compliance assessment using the spherical formula for underground BSs, one possible solution is to apply as correction coefficient to the spherical formula a ratio (see clause 9.3) of 6 (when rounded up to an integer).

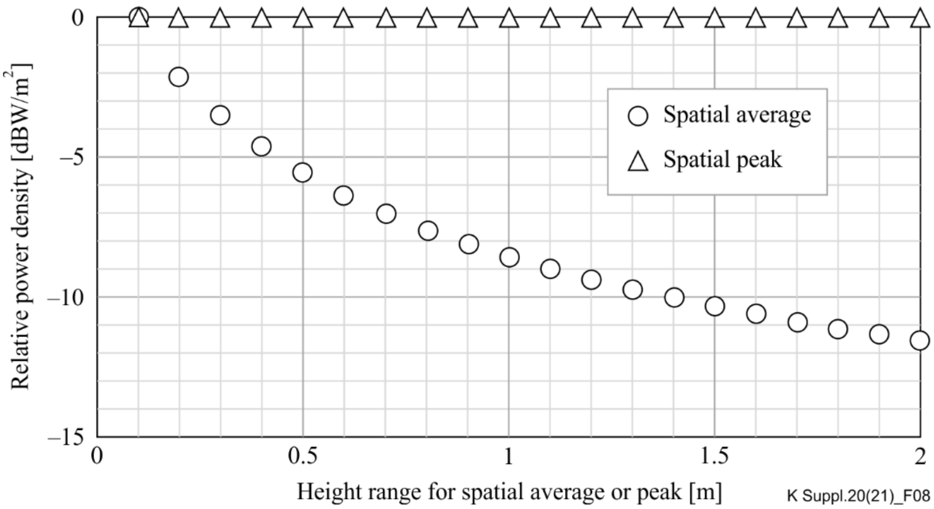


Figure 8 – An example result of the dependencies of the spatial average and peak exposure levels in the vertical direction on height ranges for a spatial averaging scheme based on the 20-point method (at the evaluation point directly above the antenna in the 2 GHz band)

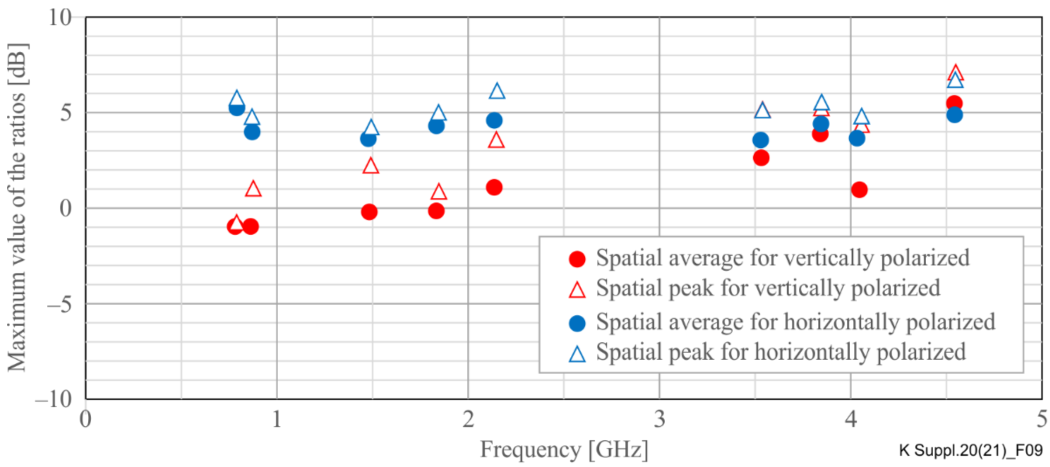


Figure 9 – Dependency on the frequency of the maximum value of the ratios of exposure levels by numerical analysis to those by the conventional spherical formula in each condition

11 Conclusion

Exposure evaluations based on measurements of power densities and numerical analysis of EMF distribution using the FDTD method for the underground BS were carried out using the measurement and full-wave computation methods specified in [IEC 62232], [ITU-T K.61] and [b-MIC] introduced in [ITU-T K.91].

It was confirmed by the exposure evaluation based on the measurement that the maximum power density normalized by EIRP, 1 W per MIMO branch, was lower than the reference levels for spatial averaging specified in [b-MIC], which are almost the same as those given in [b-ICNIRP].

It was confirmed by the exposure evaluation based on full-wave computation that a shorter height range spatial averaging scheme based on the 20-point method for people with relatively short stature is necessary and a correction coefficient of 6 for the spherical formula may be needed to avoid underestimation of exposure levels from underground BSs.

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