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Measurement of non ionizing radiation

Technical Report: Measurement Method for LTE Base Stations

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1 Introduction

1.1 The Ordinance relating to Protection from Non-Ionising Radiation

The “Ordinance relating to Protection from Non-Ionising Radiation” (ONIR) [1] published in 1999 defines

- **Exposure limit values** for electromagnetic fields for frequencies ranging from 0 Hz to 300 GHz (based on ICNIRP).

- The so called **“installation limit values”** that are more stringent than the exposure limit values. These limit values have been introduced as precautionary limitation of emissions. They apply to the radiation emitted by one installation in its **reference operating mode,** which corresponds (in case of mobile telecommunication systems) to the operation at maximum “speech and data” traffic and at maximum transmission power. They have to be respected at places of sensitive use, e.g. apartments, offices, schools, children’s playgrounds etc.

In other words, compliance assessment of a mobile phone base station includes a measurement of the electric field strength at a defined time as well as an **extrapolation of the measured values to the reference operating mode**.

1.2 Measurement recommendations

Therefore, the compliance assessment of an installation with the regulation is not only an electric field-strength measurement process, but it needs additional calculations in order to determine as correctly as possible the field strengths that are expected in the reference operating mode. In order to harmonize the way these measurements and extrapolations are performed, a series of technology specific “measurement recommendations” has already been published: GSM [2], UMTS [4], Broadcasting [5], and EDGE [3].

1.3 Motivation and scope of this document

With the introduction of Long-Term-Evolution (LTE) as a new technology in the mobile telecommunication networks it is necessary to develop a reference method for measuring field levels of LTE installations in indoor and outdoor environments. The method should be

- robust
- provide extrapolations that are as accurate as possible, avoiding over- or underestimation of the electric field strength in the reference operating mode
- in line with the previous measurement recommendations.

1.4 Outline

As in the case of previous measurement recommendations, two different methods are proposed here:

- The code-selective method allows the assessment of the compliance or non-compliance of an installation with the installation limit value. As such it is to be considered as the **reference method.**
- The spectral method does not allow the distinction of two different cells of the same operator/installation. Moreover, it suffers from overestimation of the extrapolated field strength for the reference operating mode. While it is able to demonstrate compliance of an installation with the regulation, it fails to finally prove non-compliance even if the extrapolated field strength exceeds the installation limit value. This method is therefore considered as **an approximate method** (“Orientierende Messung”).

1.5 Application and outlook

This document can be applied for compliance tests of LTE base stations with respect to the ONIR, until an official measurement recommendation of the Federal Office of Metrology (METAS) and the Federal Office for the Environment (FOEN) is published.

2 Code-selective method

2.1 Measurand

The code-selective method is based on the determination of the radiated field produced by the Cell-specific Reference Signal (CRS) of the downlink signal transmitted on port 0. The CRS is mapped to the resource elements R_0 which are distributed over the full bandwidth of the LTE downlink signal on antenna port 0 (see Annex A). The CRS transmitted by antenna port 0 (CRS_0) carries information on the cell identity number (0 to 503). Measurement of the CRS_0 requires a code-selective field probe, a measuring receiver or a spectrum analyzer capable of decoding CRS signals and of quantifying their power.

The bandwidth of the measuring instrumentation to quantify the CRS_0 is not specified. It should have a minimum value of 6 LTE resource blocks (1.08 MHz, see Annex A), but can also cover the total LTE downlink signal bandwidth.

As in the previous measurement recommendations, the spatial maximum of the CRS_0 signal of each LTE cell has to be found in the measurement volume, taking into account:

- Standing waves in the measurement volume
- Polarization of the measuring antenna
- Orientation (azimuth and elevation) of the measuring antenna.

The spatial maximum of the electric field is determined taking into account the same measurement conditions as mentioned in the previous recommendations

- Minimum distance to the walls, floor, ceiling, furniture and windows : 50 cm
- Height above the floor between 0.5 m and 1.75 m
- Methods for finding the spatial maximum documented as variant 1 or variant 2 [2, 4].

The receiving antenna used for the measurements should be of small dimensions so that it may easily be used indoors. It must be calibrated.

2.2 Appreciation value

For each LTE-cell *i* of the base station (resp. installation), an extrapolation factor $K_i^{R_o}$ is defined as:

$$K_i^{R_o} = \sqrt{\frac{P_{i,\mathrm{permitted}}}{P_i^{R_o}}} \ ,$$

with

$K_i^{R_o}$	Extrapolation factor for cell i.
$P_i^{R_o}$	Actual radiated power (ERP) per resource element of the reference signal CRS_0 of the cell i in W.
$P_{i,\mathrm{permitted}}$	Permitted radiated power (ERP) for cell i in W (including the signal of all antenna ports of the cell).

Note

1. The actual power of the reference signals $P_i^{R_o}$ is defined as the power per resource element (R_0 power), and not as the total power of the CRS_0 signal.

2. The permitted power $P_{i,\mathrm{permitted}}$ and the actual power of the reference signals $P_i^{R_o}$ are provided by the network operator [2, 4].

The measured value of the electric field strength has to be extrapolated to the reference operating mode:

$$E_{i,h} = E_{i,\max}^{R_o} \cdot K_i^{R_o} \ ,$$

with

$E_{i,h}$	Extrapolated value of the electric field strength for the cell i in V/m.
$E_{i,\max}^{R_0}$	Spatial maximum of the electric field strength per resource element of the reference signal CRS_0 of cell i within the measurement volume, in V/m. (in general this value is the average power of all measured resource elements R_0).
$K_i^{R_o}$	Extrapolation factor for cell i.

Note:
The spatial maximum of the electric field strength $E_{i,\max}^{R_0}$ of the reference signal CRS_0 is measured in terms of “electric field strength per resource element” (electric field strength of R_0), and not in terms of the total field strength of the CRS_0 signal. In the latter case the measurement instrumentation does only provide the total electric field strength, an adapted scaling of the measured total electric field strength value to that of only one resource element must be performed.

All LTE cell-specific extrapolated electric field strength values are then summed together as:

$$E_h = \sqrt{\sum_{i=1}^{n} E_{i,h}{}^2},$$

with

E_h	Extrapolated electric field strength of LTE for a given network, in V/m
$E_{i,h}$	Extrapolated electric field strength measurement for cell i, in V/m
n	Number of cells of the base station respectively of the installation

Finally, the appreciation value E_B is obtained by summing over the contributions $E_{\mathrm{Network}_j,h}$ of all networks belonging to the same installation:

$$E_B = \sqrt{E_{\mathrm{Network}_1,h}{}^2 + E_{\mathrm{Network}_2,h}{}^2 + \ldots}$$

Examples of calculations are found in Annex B.

For base stations running GSM or UMTS services simultaneously, also these signals have to be taken into account and E_B has to be determined according to [4] (chapter 9).

2.3 Compliance assessment

With the code-selective method the compliance or non-compliance of an installation can be unequivocally demonstrated:

- $E_B \le E_{\mathrm{limit}}$ installation fulfills the requirements
- $E_B > E_{\mathrm{limit}}$ installation does not fulfill the requirements

As in the existing recommendations [2, 4, 5], the expanded measurement uncertainty U (k=2) is not taken into account directly in the compliance assessment (so called “shared risk” or “simple acceptance” according to [11]). However, it must

- include a contribution of ±15% (k=1) for the sampling of the measurement volume
- not exceed the value of ± 45% (k=2).

The measurement uncertainty has to be determined similarly as for the code selective measurements of UMTS base stations [4].

2.4 Discussion and comments

The choice of the cell reference signal CRS_0 as the signal to be measured is motivated by the fact that:

- The signal CRS_0 is emitted by antenna port 0 only. The electric field produced by this signal will be, contrarily to the synchronization signals, free of constructive or destructive interference by signals transmitted by the other ports of the antenna. The electric field strength of the signal CRS_0 or R_0 respectively at a given location is therefore independent of the polarization angle between the radiating elements of the antenna port number 0 and the radiating elements of other antenna ports. This is very similar to GSM and to UMTS where the control channel is also emitted by one antenna port only.
- The signal CRS_0 is always sent independently of the number of ports used in MIMO transmission schemes (for limitations cf. section 2.5).

2.5 Limitations

1. The CRS signals are only available in case of a subcarrier spacing Δf of 15 kHz. They are not available for a subcarrier spacing Δf of 7.5 kHz which is foreseen for MBMS (Multimedia Broadcast and Multicast Service).

2. The method has been established for FDD systems. Its principles may also be applied to TDD systems. In this case, small adaptations may be necessary.

3. The method based on the measurement of the reference signal CRS_0 is valid as long as the antennas of all ports are located at the same place.

3 Frequency selective method

3.1 Measurand

The frequency selective method is based on the power of both synchronization signals. The primary synchronization signal (PSS) and the secondary synchronization signal (SSS) are transmitted in one Orthogonal Frequency-Division Multiplex (OFDM) symbol each, every 10 slots, over a bandwidth of 62 subcarriers (930 kHz + 15 kHz for the center-subcarrier according to section 6.12 of [6]). Measurements of the synchronization signals require a spectrum analyzer with true RMS-detector, a minimum resolution bandwidth of 945 kHz (typical resolution bandwidth of 1 MHz) and a maximum hold-function. The measurements are performed in “Zero Span” mode, and the sweep time must be chosen so that the measuring time per pixel does not exceed 70 µs, the duration of one OFDM symbol being about 71.5 µs. The motivations for this restriction are detailed in [9, 10].

The spatial maximum of the synchronization signals should be measured similarly to the previous measurement recommendations (as mentioned in the previous section).

3.2 Appreciation value

For each LTE-cell *i* of the base station, an extrapolation factor K_i^{SS} is defined as:

$$K_i^{\mathrm{SS}} = \sqrt{\frac{P_{i,\mathrm{permitted}}}{\min\left(P_i^{\mathrm{PSS}}, P_i^{\mathrm{SSS}}\right)}},$$

with

K_i^{SS}	Extrapolation factor for cell i.
P_i^{PSS}	Actual radiated power (ERP) per resource element of the primary synchronization signal of the cell i in W.
P_i^{SSS}	Actual radiated power (ERP) per resource element of the secondary synchronization signal of the cell i in W.
$P_{i,\mathrm{permitted}}$	Permitted radiated power (ERP) for cell i in W (including the signal of all antenna ports of the cell).

Note

1. The actual power of the synchronization signals P_i^{PSS} and P_i^{SSS} are defined as the power per resource element, and not as the total power of the synchronization signals.

2. The permitted power $P_{i,\mathrm{permitted}}$ and the actual power of the synchronization signals P_i^{PSS} and P_i^{SSS} are provided by the network operator [2, 4].

The measured value of the electric field strength has to be extrapolated to the reference operating mode:

$$E_h = E_{\max}^{\mathrm{SS}} \cdot \max_{i=1..n}\left(K_i^{\mathrm{SS}}\right),$$

with

E_h	Extrapolated LTE electric field strength for a given network, in V/m
$E_{\max}^{\mathrm{SS}}$	Spatial maximum of the electric field strength (per resource element) of the synchronization signals within the measurement volume, in V/m.
K_i^{SS}	Extrapolation factor for cell i.
n	Number of cells of the base station respectively of the installation

Note:
The spatial maximum of the electric field strength $E_{\max}^{\mathrm{SS}}$ of the synchronization signals is measured in terms of "electric field strength per resource element", and not in terms of the total electric field strength of the synchronization signals. In case the measurement instrumentation does only provide the total electric field strength, an adapted scaling of this total electric field strength value to only one resource element must be performed as follows:

$$E_{\max}^{\mathrm{SS}} = E_{\max}^{\mathrm{measured}} \cdot \sqrt{\frac{1}{62}} \,,$$

with

$E_{\max}^{\mathrm{measured}}$ Max & Hold value measured over the whole bandwidth of the spectrum analyzer.

Finally, the appreciation value E_B is obtained by summing over the contributions of all network operators and services as in the previous section (examples in Annex B).

3.3 Compliance assessment

With this method, compliance of an installation can be shown while non-compliance cannot:

- $E_B \le E_{\mathrm{limit}}$ installation fulfills the requirements
- $E_B > E_{\mathrm{limit}}$ no assessment possible. For clarification a code selective measurement is necessary.

3.4 Discussion

The frequency selective method does not provide the information necessary to conclusively assess the non-compliance of an installation with the regulation. This is due to an overestimation of the extrapolated electric field strength. This overestimation arises from the following effects:

- Despite the fact that the synchronization signals carry cell identification information, this information is not decoded by conventional spectrum analyzers. Therefore, the extrapolation proposed here is based on the maximum of all extrapolation factors which is applied to each cell of the installation.

- The extrapolation factor introduced here is defined as though the synchronization signals were transmitted by one antenna port only. If the synchronization signals are transmitted by two antenna ports (which is also possible according to [6]), the resulting synchronization signal at the measuring point may be a constructive addition of both synchronization signals, depending on the polarization of the radiating elements of both antenna ports. The extrapolation factor should theoretically be slightly reduced to take this feature into account, which is not feasible in practice. Therefore, a small overestimation will arise. However, this overestimation should be negligible in practice, especially if the radiation emitted from both antenna ports (in case of a 2-port antenna) is perpendicularly polarized.

- The scaling of the maximum signal value over the measurement bandwidth $E_{i,\max}^{\text{measured}}$ to the electric field strength $E_{\max}^{\text{SS}}$ of the synchronization signals "per resource element" is performed independently of the resolution bandwidth of the spectrum analyzer. If the resolution bandwidth is larger than 945 kHz, a slight overestimation will arise.

3.5 Limitations

The method suffers from the same limitations as the code selective approach.

4 Literature

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5 Annex A: Basics in LTE (informative)

5.1 Downlink resource grid

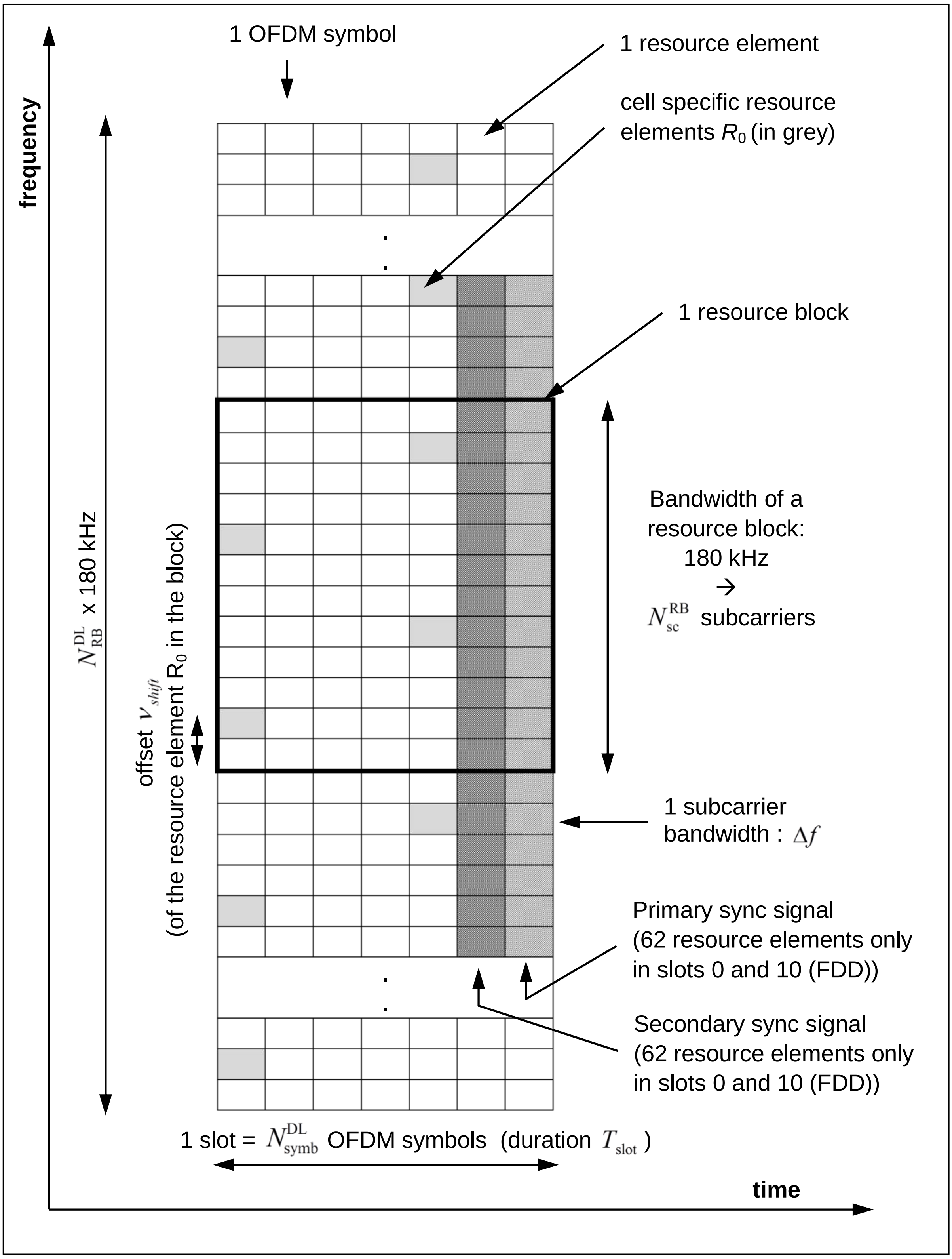

Figure A1: LTE downlink resource grid (reproduced from [6]).

Legend

Δf	Subcarrier spacing equal to 15 kHz (note: 7.5 kHz is also foreseen for MBMS (Multimedia Broadcast and Multicast Service)). In this case the CRS (cell reference signals are not available).
T_{slot}	Slot duration: 0.5 ms for FDD.
$N_{\text{symb}}^{\text{DL}}$	Number of OFDM symbols in a downlink slot: 7 or 6 depending on the configuration (normal cycling prefix or extended cycling prefix, see section 6.2.3 of [6]).
$N_{\text{RB}}^{\text{DL}}$	Downlink bandwidth configuration, expressed in multiples of $N_{\text{sc}}^{\text{RB}}$. $N_{\text{RB}}^{\text{DL}}$ is ranging from 6 to 110: $6 \le N_{\text{RB}}^{\text{DL}} \le 110$
$N_{\text{sc}}^{\text{RB}}$	Resource block size in the frequency domain, expressed as a number of subcarriers. $N_{\text{sc}}^{\text{RB}} = 12$ for $\Delta f = 15\,\text{kHz}$.
v_{shift}	Cell specific frequency shift depending on the cell ID number.

6 Annex B: Examples

A network operator provides LTE services using 3 antennas mounted on a mast. All three cells operate in the 1800 MHz band. The main beams of the antennas are 120 degrees from each other as shown in the following Figure. Technical data of the installation are listed in Table 1. According to the ONIR the installation limit value is 6 V/m.

Cell ID	Antenna	Main beam direction	LTE downlink	Actual power (ERP) of one R_0 resource element	Actual power (ERP) of one SS resource element	Total permitted radiated power (ERP)	Extrapolation factor $K_i^{R_o}$	Extrapolation factor K_i^{SS}
6	1	30º	Center: 1838 MHz Channel bandwidth: 10.0 MHz Number of OFDM symbols per time slot: $N_{\text{symb}}^{\text{DL}} = 7$	333 mW	333 mW	400 W	34.64	34.64
7	2	150º		333 mW	333 mW	200 W	25.00	25.00
8	3	270º		333 mW	333 mW	200 W	25.00	25.00

Table 1: Technical data of the installation. (Note: a system bandwidth of 9 MHz = 600 x 15 kHz means a channel bandwidth of about 10 MHz).

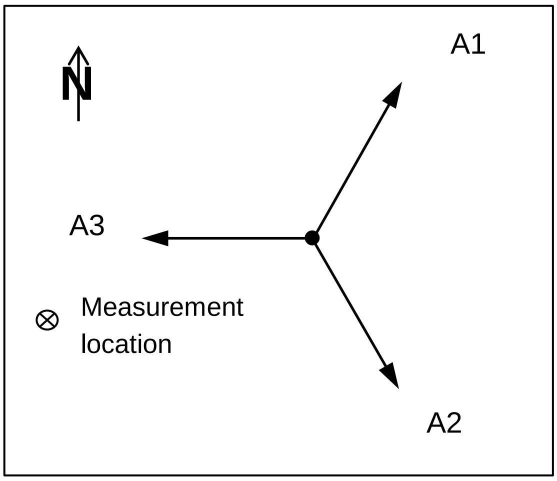

Figure 1: representation of an installation with the three antennas and the measurement place.

6.1 Code-selective measurement

With code-selective measurement equipment, the electric field strength of each cell can be measured separately. Therefore, for each CRS_0 signal the spatially maximum field value $E_{i,\max}^{R_0}$ within the measurement volume is measured. The extrapolation factors as well as the extrapolated field values are reported in Table 2.

Cell ID	Antenna	Measured value $E_{i,\max}^{R_0}$	Extrapolation factor $K_i^{R_o}$	Extrapolated electric field strength $E_{e,j}$
6	1	6 mV/m	34.64	0.21 V/m
7	2	16 mV/m	25.00	0.40 V/m
8	3	151 mV/m	25.00	3.78 V/m

The value of the electric field strength extrapolated to the reference operating mode is

$$E_B = E_h = \sqrt{\sum_i {E_{i,h}}^2} = \sqrt{0.21^2 + 0.40^2 + 3.78^2} \text{ V/m} = 3.80 \text{ V/m}$$

This value is lower than the limit of 6 V/m. The installation is considered as compliant.

6.2 Frequency-selective measurement

The spatial maximum value of the electric field strength measured with a spectrum analyzer having a resolution bandwidth of 1 MHz is found to be 1.25 V/m (measured over the full bandwidth). The electric field per resource element is determined by:

$$E_{\max}^{\text{SS}} = E_{\max}^{\text{measured}} \cdot \sqrt{\frac{1}{62}} = \frac{1.25 \text{ V/m}}{\sqrt{62}} = 0.16 \text{ V/m}$$

The extrapolation factor is the maximum value of all extrapolation factors K_i^{SS} in Table 1, in our example: 34.64. The extrapolated field value is therefore:

$$E_B = E_h = \max_i \left(K_i^{\mathrm{SS}}\right) \cdot E_{\max}^{\mathrm{SS}} = 34.64 \cdot 0.16 \ \mathrm{V/m} = 5.54 \ \ \mathrm{V/m}$$

The value of the electric field strength extrapolated to the reference operating mode is lower than the limit value of 6 V/m. The installation is considered compliant.

7 Annex C: Definitions, symbols and abbreviations

CRS	Cell-specific Reference Signal
CRS_0	Cell-specific Reference Signal transmitted on antenna port 0
CRS_1	Cell-specific Reference Signal transmitted on antenna port 1
EDGE	Enhanced Data Rates for GSM Evolution
ERP	Effective Radiated Power
FDD	Frequency Division Multiplex
GSM	Global System for Mobile Communication
ICNIRP	International Commission on Non-Ionizing Radiation Protection
LTE	Long-Term-Evolution
OFDM	Orthogonal Frequency-Division Multiplexing
ONIR	Ordinance relating to Protection from Non-Ionising Radiation
PSS	Primary Synchronization Signal
R_0	Resource element used for CRS transmission on antenna port 0
SSS	Secondary Synchronization Signal
TDD	Time Division Multiplex
UMTS	Universal Mobile Telecommunications System
E_B	Acceptance value for the installation in V/m
E_{limit}	Limit electric field value, in V/m
E_h	Extrapolated LTE field strength, in V/m
$E_{i,h}$	Extrapolated field strength measurement for cell i, in V/m

$E_{i,\max}^{R_0}$	Spatial maximum (within the measurement volume) of the electric field strength per resource element of signal CRS_0 of cell i, in V/m
$E_{\max}^{\mathrm{SS}}$	Spatial maximum (within the measurement volume) of the electric field strength per resource element of the synchronization signals, in V/m
$E_{\max}^{\mathrm{measured}}$	Max & Hold value measured over the whole bandwidth of the spectrum analyzer, in V/m
$E_{\mathrm{Network}_j,h}$	Extrapolated field strength measurement related to network j
i	Identification number of the base station cell
$K_i^{R_0}$	Extrapolation factor for cell i based on the cell reference signal R_0
K_i^{SS}	Extrapolation factor for cell i based on the synchronization signals
n	Number of cells of the base station respectively of the installation
$N_{\mathrm{symb}}^{\mathrm{DL}}$	Number of OFDM symbols in a downlink slot
$N_{\mathrm{RB}}^{\mathrm{DL}}$	Downlink bandwidth configuration, expressed in multiples of $N_{\mathrm{sc}}^{\mathrm{RB}}$
$N_{\mathrm{sc}}^{\mathrm{RB}}$	Resource block size in the frequency domain, expressed as a number of subcarriers
$P_i^{R_0}$	Actual radiated power (ERP) per resource element of the reference signal R_0 of the cell i in W
P_i^{PSS}	Actual radiated power (ERP) per resource element of the primary synchronization signal of the cell i in W
P_i^{SSS}	Actual radiated power (ERP) per resource element of the secondary synchronization signal of the cell i in W.
$P_{i,\mathrm{permitted}}$	Permitted LTE radiated power (ERP) for cell i in W
T_{slot}	Slot duration
Δf	Subcarrier spacing
ν_{shift}	Cell specific frequency shift