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DEPUTY MINISTRY OF RESEARCH, INNOVATION AND DIGITAL POLICY

DEPARTMENT OF ELECTRONIC COMMUNICATIONS

5G Near Radio

Transitional procedure for the evaluation of radio frequency electromagnetic field exposure of 5G base stations up to 6 GHz

Contents

Acronyms

5G	Fifth Generation
BS	Base Station
CB	Compliance Boundary
DM-RS	Demodulation Reference Signal
EMF	Electromagnetic field
EUT	Equipment under test
FDD	Frequency division duplex
ICNIRP	International Commission on Non-Ionizing Radiation Protection
LTE	Long Term Radio
NR	Near Radio
PBCH	Physical Broadcast Channels
PSS	Primary Synchronisation Signal
RE	Resource Element
RF	Radiofrequency
RBS	Radio Base Station
SA	Specific energy absorption
SAR	Specific energy absorption rate
SSS	Secondary Synchronisation Signal
TDD	Time division duplex
TER	Total Exposure Ratio
TX	Transmitter

Executive Summary

The scope of this report is to present a transitional procedure for the evaluation of radio frequency (RF) electromagnetic field (EMF) exposure of fifth generation (5G) radio base stations (RBS) that employ massive Multiple-In Multiple-Out (MIMO) and beamforming.

The 5G Near Radio (NR) technology covers two frequency ranges (from 450 MHz to 6 GHz and from 24.5 GHz to 52.6 GHz), the present report is restricted to the first frequency range up to 6 GHz.

Even though the next generation of mobile communications (5G) is a key enabling technology for digital transformation and a key component of gigabit networks, the adoption of new technological features such as the use of millimeter wave (mmWave) spectrum, beamforming and small cells has resulted in heightened concerns about exposure health effects.

At present, there is no standardized protocol for the evaluation of EMF emissions in the vicinity of 5G base stations. The only standard that covers preliminary aspects of 5G technologies is EN 62232:2017, however the procedures and methods described require adaptations in order to consider the specificity of 5G technology. This will be covered in the new Edition of the updated EN 62232. On the other hand, the human health exposure limits are clearly documented and were recently enhanced with the recent ICNIRP 2020 Guidelines.

Finally, the proposed procedure is based on principles and methods described in EN 62232 and includes additions to account for 5G specificities that are extracted from scientific reports. Two methods are proposed:

a) Frequency selective.
b) Code selective.

The code selective method offers several advantages over the frequency selective method and is therefore proposed as the reference method for the future. Until the new edition of the updated EN 62232 is released to include 5G technology and the relevant entities performing EMF measurements are accredited, **Frequency Selective method is requested to be performed**.

Scope

The scope of this report is to present a transitional procedure for the assessment of radio frequency (RF) electromagnetic field (EMF) exposure for the fifth generation (5G) radio base stations (RBS) employing massive Multiple-In Multiple-Out (MIMO) and beamforming.

Currently, there is no standardized protocol for the evaluation of EMF emissions from 5G Near Radio (NR) base stations (BS) and no regulated method to account and consider for the extrapolation to the maximum theoretical exposure. In this context, the report scopes to present a transitional procedure for evaluating EMF exposure levels of 5G base stations by considering the exposure procedure outlined in EN 62232:2017 [1] and providing detailed information on how the acquired exposure level components can be extrapolated.

The proposed procedure shall:

- Allow accurate extrapolations that do not over- or under-estimate the results.
- Consider the beam steering features of the 5G technology.
- Account for the variability of the transmission direction and antenna pattern from adaptive antennas.
- Apply to both frequency division duplex (FDD) as well as to time division duplex (TDD) modes.

Finally, the presented extrapolation methods are based on recent scientific publications that consider the utilization of frequency selective analyzers for frequency and code exposure measurements.

1. Background theory

5G NR is a next-generation global wireless standard that enables the anticipated future technological evolution for increased operational performance (e.g. increased spectral efficiency, ability to connect millions of devices, higher data rates, low latency). The main usage scenarios for 5G as defined by ITU-R include:

- Enhanced Mobile Broadband (eMBB) to deal with hugely increased data rates, high user density and very high traffic capacity.
- Massive Machine-type Communications (mMTC) for the Internet of Things (IoT).
- Ultra-reliable and Low Latency Communications (URLLC) to cater for safety-critical and mission critical applications.

Similarly, to prior technologies such as the Long-term Evolution (LTE), 5G NR uses orthogonal frequency division multiple access (OFDMA) in the downlink in a frequency division duplex (FDD) or time division duplex (TDD) mode. Conversely, the main differences from predecessor technologies (1G – 4G) from a human exposure perspective is the:

- Usage of massive and agile beam forming.
- Reduction of the level of signals transmitted independently of the current traffic load and user behavior.

Higher bandwidth modes are one of the technology components of 5G employed to achieve higher data rates. They are only available at significantly higher carrier frequencies compared with today's cellular network implementations below 6 GHz (see Figure 1).

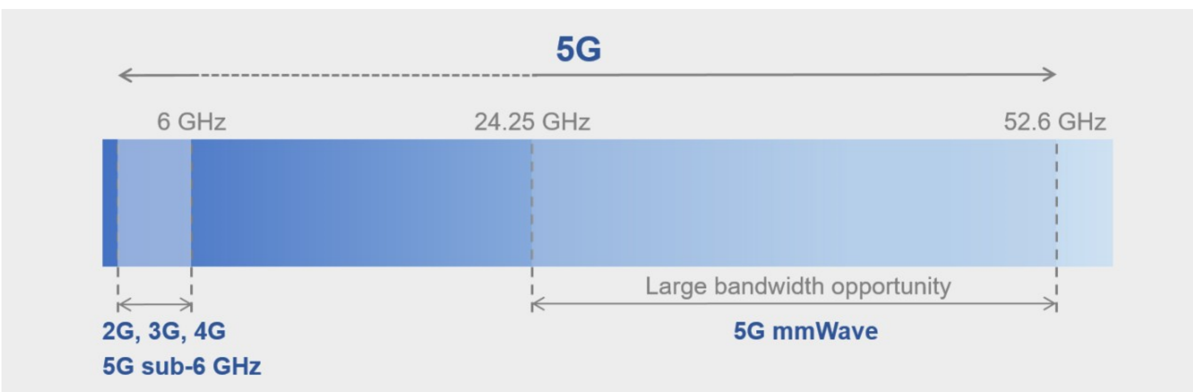

Figure 1. 5G NR frequency allocation.

3GPP has defined a frequency range of 24.25 GHz to 52.6 GHz for 5G NR cmWave and mmWave operation, which is a technological breakthrough for the mobile industry (spectrum above 6 GHz is a new area). The single carrier channel bandwidth and carrier aggregation determine the overall bandwidth requirements. A maximum channel bandwidth per 5G NR carrier of 100 MHz for the sub-6 GHz range and 400 MHz for the mmWave range plus multiple carrier aggregation leads to a bandwidth requirement of up to 2 GHz.

In 5G NR the cell search concept is similar to the one utilized in Long-Term Evolution (LTE) since the Primary Sync Signal (PSS) and the Secondary Sync Signal (SSS), which form part of the PBCH block (see Figure 2), are used in order to decode the Physical Cell ID (PCI). Additionally, the payload data for 5G NR are transmitted on the Physical Downlink Shared Channel (PDSCH), whereas the synchronization and identification signals are transmitted on the PBCH channels (on up to 4, or 8 different SS/PBCH beams). Similarly, the PDSCH channel is transmitted on other beams that are generally more focused than the SS/PBCH beams (the beam intensity of PDSCH depends on the payload data and in this sense varies in time).

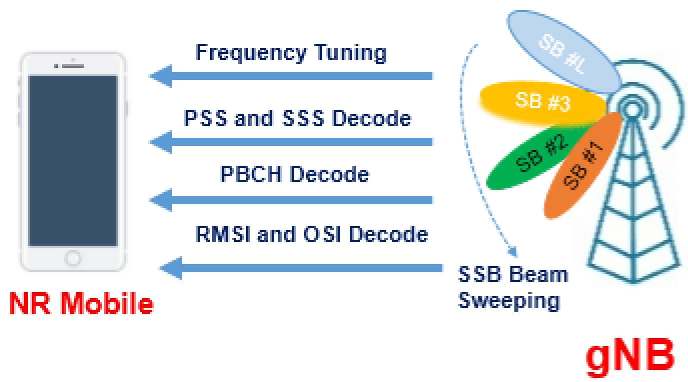

Figure 2. 5G downlink signaling overview.

Both the PSS and SSS are signals inside the physical broadcast channel (SS/PBCH) block. The SSS is part of the SS/PBCH blocks which are distributed over a bandwidth of 3.6 MHz up to 7.2 MHz (for carrier frequency up to 6 GHz) within the NR downlink signal. The entire block is 240 subcarriers broad and 4 symbols long. The PSS and SSS are 127 subcarriers broad and 1 symbol long (see Figure 3). Furthermore, most 5G base stations are expected to use TDD, in which uplink and downlink are multiplexed over time slots. The reason for TDD preference is the improved utilization of the available frequency spectrum since more data is usually required for the downlink than for the uplink.

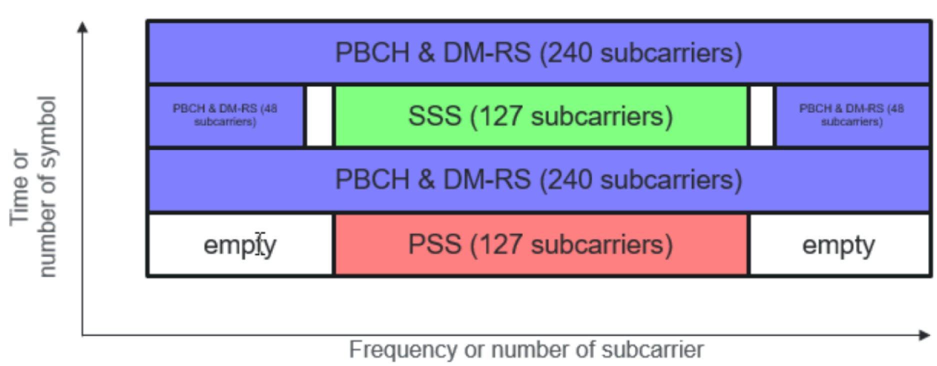

Figure 3. Structure of the SS/PBCH block of 5G architectures.

Currently no standardized 5G EMF measurement method exists to describe the procedure undertaken and to allow extrapolation to the maximum theoretical exposure. The main challenge remains the impact of beamforming for extrapolation (the dynamic range of 5G may lead to variations of >10 dB). On the other hand, considering the utilization of RF EMFs in a multitude of approaches for modern telecommunications and the growing concerns of EMFs implications to human health, the guidelines for exposure to RF EMFs (published by ICNIRP two decades ago, ICNIRP 1998 [2]) were recently updated to the ICNIRP 2020 [3] Guidelines in order to consider current and future technologies. In particular, the new guidelines have incorporated a number of important additions and changes, particularly for EMF frequencies above 6 GHz where future 5G technologies will operate, which have the result of reducing the maximum magnitude of localized exposure that a person can receive. This is particularly important given that it is yet unknown how 5G technologies will develop in the future, and so a more robust system is required to ensure that harm cannot occur. Another important point to be made is that the ICNIRP 2020 Guidelines protect against all adverse health effects, regardless of whether they occur immediately after exposure, or take a long time to develop. ICNIRP 2020 Guidelines consider all potential adverse health effects and sets restrictions to ensure that none occur, regardless of the mechanism of interaction between the exposure and the body. The lowest exposure levels that can cause adverse health effects are due to thermal mechanisms, and so restrictions have been set based on the thermal effects, as these will protect against any other effects that could occur at higher exposure levels.

1.1 Challenges and differences of 5G

In previous cellular technologies (GSM, UMTS and LTE), always-on reference signals were used as reference signals for precise channel estimation and cell-specific synchronization. 5G NR is a completely new approach regarding cell-specific signals since 5G NR RBS broadcasts only a minimum amount of cell-specific signals. The large bulk of signals are payload user equipment (UE) specific. Another important difference is that the appearance of signals both in the frequency and time domain are primarily dependent on data traffic. The only always-on signal is the synchronization signal block (SSB) that contains the primary and secondary synchronization signals (PSS and SSS) and the physical broadcast channel (PBCH). As in LTE, the PSS and SSS in 5G NR represent the physical cell identity (PCI), and the PBCH carries the master information block (MIB) plus a few additional payload bits. The following Table summarizes the main differences between 4G and 5G technologies that are relevant to EMF exposure evaluations.

Table 1. Main differences between 5G and predecessor 4G technologies.

Feature	4G	5G
Antenna pattern	Fixed, equal for signaling and all data	Beam forming
Typical beam pattern	Azimuth: 60° or 360° Elevation: ≈ 10°	Depending on type of signal and antenna
Frequency range	400 MHz to 6 GHz	FR1: 400 MHz to 7 GHz, FR2: 28 GHz, 38 GHz, (43, 47, beyond)
RF bandwidth	≤ 20 MHz	≤ 100 MHz (FR1), ≤ 400 MHz (FR2)
Signaling	In mid of frequency band, always on, same pattern as data	At fixed frequencies, not necessarily in same band, beam constant or scanning

Reference symbols	Cell specific, always transmitted, distributed over the bandwidth	Flexible and configurable reference signal concept. Only SSB is "always on"

The above mentioned technological differences impose challenges for the extrapolation of the measured emission to maximum theoretical exposure conditions. Prior scientific work demonstrates that fundamental extrapolation factors that need to be considered for 5G EMF exposure evaluations include:

- Projection of the SSB power on the total 5G NR carrier spectrum: Synchronization signal blocks only have a bandwidth of 3.6 MHz to 56 MHz depending on the subcarrier spacing. The total bandwidth of 5G NR carrier can be up to 400 MHz and therefore information is required from network operators in order to calculate the extrapolation factor.
- Uplink and downlink relation factor: In the case of TDD, the relation between uplink and downlink significantly affects the power radiated by the gNodeB. The relation factor depends on the network configuration that has to be requested from the network operators.
- Beam/gain offset between SSB and data beams: In 5G RBS data/UE specific beams are expected to have a lower beamwidth and/or more power than SSB beams. Information on the beam/gain between the measurable SSB and downlink data beams has to be requested from the network operators or infrastructure suppliers.

The following Table summarizes the expected impact of 5G technology features on the EMF level.

Table 2. Expected impact of 5G technology features on EMF [4].

Feature	Relevance to EMF	Expected EMF Increase (+)/Decrease (-)
MIMO	Increased number of antennas radiating power. Impact of computing the radiated power when assessing the compliance with EMF limits.	-/+ The impact on the EMFs levels depends on the specific MIMO configuration and on the adopted approach for measuring the EMF levels.
Beamforming	Directionality control of the radiated power. Power concentrated into selected locations.	- General decrease with respect to currently deployed BSs. + Increase in selected locations.
mmWave	Path loss increase of radiated signals on mmWave bands.	- (Possible) decrease of BSs exploiting micro-waves.
Small Cells	Installation of additional sources of power. Less power required to macro cells.	- (Possible) decrease with respect to the current cellular network. + (Possible) increase in proximity to the small cells.
Offoading	(Possible) reduction of radiated power from the most loaded cells.	- (Possible) decrease with respect to the current cellular network.
Softwarization	Sharing of the hardware infrastructure by multiple operators. Fewer antennas installed in the shared sites.	- Large decrease with respect to the case in which each operator installs its own physical equipment in the same site.

1.2 EMF standardization for 5G

At present, there is no standard for the exposure evaluation of 5G technologies. It is expected that the new version of IEC 62232 Edition 3 will provide a robust methodology for 5G RBS EMF evaluations. The following Table summarizes the standards that are relevant to 5G technologies.

Table 3. EMF standards and recommendations relevant to 5G.

International	
1	ICNIRP (2020): Guidelines For Limiting Exposure To Time-Varying Electric, Magnetic, And Electromagnetic Fields (Up To 300 GHz)
2	IEC 62232 (2017): Determination of RF field strength and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure
3	IEC TR 62669 (2019): Case studies supporting IEC 62232 – Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure
European	
1	1999/519/EC: COUNCIL RECOMMENDATION on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)
2	2013/35/EC: Directive on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)
3	ECC Recommendation (02)04: Measuring Non-Ionizing Electromagnetic Radiation (9 kHz – 300 GHz)
4	EN 50400: Basic standard for wireless telecommunication networks when put into service
5	EN 50413: Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz – 300 GHz)
6	EN 50492: Basic standard for the in-situ measurement of electromagnetic field strength related to human exposure in the vicinity of base stations

The Department of Electronic Communications (DEC) performs and monitors EMF measurements according to the methodology described in Recommendation CEPT/ECC/REC/(02)04 entitled "Measuring Non-Ionizing electromagnetic Radiation (9 kHz - 300 GHz)" [5]. The measurement results are processed as defined in the EU Recommendation entitled "Recommendation 1999/519/EC of 12 July 1999 on the limitation of public exposure to electromagnetic fields (0 Hz - 300 GHz)" [6]. It must be noted that EN 62232 [1] will be the standard updated to specifically include 5G NR RBS EMF evaluation methods.

2. Transitional EMF measurement exposure assessment for 5G NR base stations

In this section, a transitional evaluation procedure for in-situ EMF exposure measurements for 5G NR base stations up to 6 GHz, is presented. The 5G NR technology covers two frequency ranges (from 450 MHz to 6 GHz and from 24.5 GHz to 52.6 GHz), the **present report is restricted to the first frequency range up to 6 GHz**.

Note: The proposed procedure is based on Clause 6.3 EN 62232 [1] which will be updated in order to specifically include 5G NR RBS. Two methods are proposed: a) Frequency Selective and b) Code Selective method.

To assess the conformity of an installation with the legal requirements, a measurement of the electric field strength and additional calculations are needed. Overall the code selective method offers the following advantages over the frequency selective method:

- Independent of traffic situation.
- Operates with beamforming.
- Allows the distinction of two different cells of the same operator/installation.
- It does not react on signals emitted by mobile phone (important in TDD systems, 5G NR will be mainly used in TDD mode).
- Does not suffer from over-estimation of the extrapolated field strength of the reference-operating mode (as in the case of frequency selective method).

Additionally, the required a priori information from operators for the extrapolation method includes:

- Site beam/gain configuration.
- Visible beams information.
- Worst case condition (peak beam direction and max power).
- Obtain information from data sheet (radiation pattern and max transmitted power).

An outline of the required information from network operators is provided in Appendix A.

2.1 General requirements, source determination and site analysis

The RF exposure compliance assessment in the vicinity of a 5G 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. The objectives of the in-situ measurements include the:

- Determination whether the RF exposure levels are in compliance with applicable exposure limits and regulations, e.g. in the vicinity of an operating RBS installation.
- Acquisition of RF exposure data that are typically required for communication purposes.

The procedure described in Figure 4 shall be used to evaluate in-situ RF exposure assessment based on measurement methods, uncertainty and reporting [1].

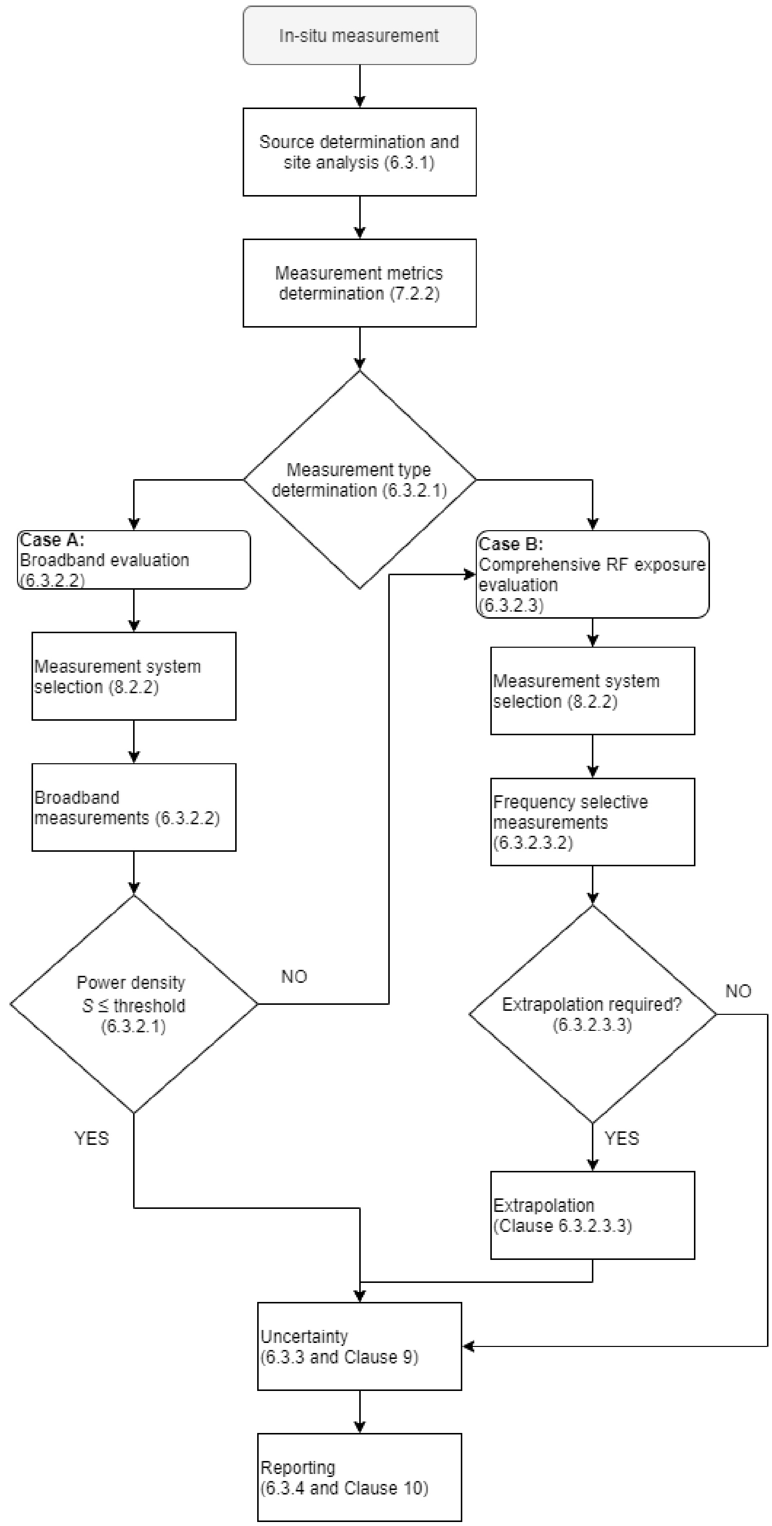

Figure 4. Alternative route to evaluate in-situ RF exposure [1].

The process shall start by identifying all relevant fixed and permanently emitting RF source installations in the surrounding area.

2.1.1 Measurement procedure

2.1.1.1 Equipment

Broadband field analyzer shall be used for Case A – Range <6 GHz.

Frequency or code selective field analyser shall be used for Case B – Range <6 GHz.

2.1.1.2 Source-environment plane definition

The source-environment plane defines the evaluation regions to be considered in the evaluation point selection based on environmental complexity and distance from the source.

All EMF measurements shall be performed at Source Region III which constitutes the far field of the source and at an environment away from obstructions (scattering objects in the vicinity of the evaluation point that may affect the results).

2.1.1.3 Measurement type selection

The selection between two evaluation approaches shall be made (Case A and Case B). Case A provides a set of results covering all sources and frequencies at one measurement area. Case B provides separate sets of field values for each emitting source present in the measurement area.

The choice of the measurement type depends on the objective of the in-situ evaluation:

- If the objective is to provide global evaluation of RF exposure level from all sources together "as observed" (i.e. no extrapolation, o\no signal spectrum differentiation) then the evaluation shall start with Case A. However, if the field assessment based on Case A is above applicable exposure limits or if it is necessary or desired to investigate the contribution from each RF source, the Case A evaluation shall be complemented by a Case B evaluation.
- If the objective is to provide a detailed evaluation of RF exposure levels (i.e. combining the contribution of all RF sources) the evaluation shall start with Case A. If the power density level is above 10 mW/m^2 (0.6 V/m) or pre-existing national requirements, the Case A evaluation shall be complemented by a Case B evaluation.
- If the objective is to provide a comprehensive evaluation of RF exposure i.e. investigating every contribution from RF sources using a frequency selective analysis, then a Case B evaluation shall be conducted.

2.1.1.3.1 Case A (broadband evaluation)

Case A corresponds to an exposure evaluation on one measurement area using broadband equipment. The evaluation shall start by performing a slow scan over the measurement area at a height of 1.5 m above ground in order to find the location of maximum exposure.

Broadband measurement shall not be used for extrapolation since without the ability to discriminate the source emission and frequency, such an extrapolation could result in large overestimation of the maximum exposure.

2.1.1.3.2 Case B (Comprehensive RF frequency evaluation)

The preferred method for assessing the health exposure impact in the vicinity of the 5G RBS is Case B either in Frequency or code selective mode. Comprehensive RF frequency selective measurements shall be conducted at all points required for the implementation of spatial averaging or sweeping method.

Measurements shall be performed at a height of 1.5 m, as shown in the Figure below from EN 50492 [4].

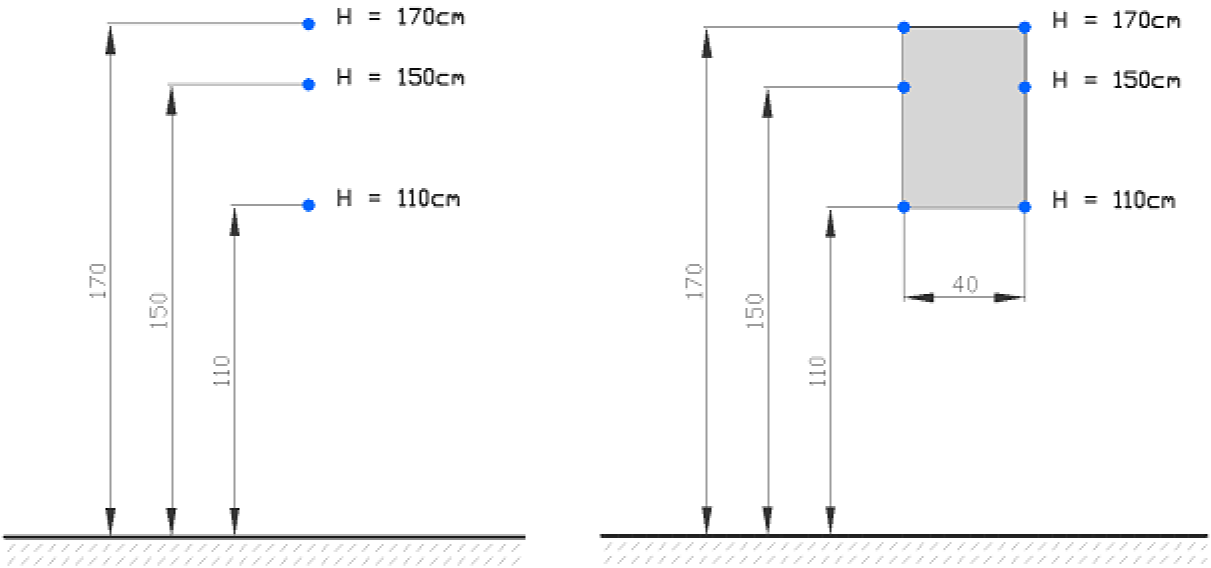

Figure 5. Measurement points for spatial averaging according to EN 50492 [7]. In the vicinity of a 5G RBS the measurement shall be taken at the height of 1.5 m.

However, depending on the location and accuracy required, the number of measurement points to be averaged may be increased as per B.3.1.4.4.2 [1]. The spatially-averaged value of the RF field strength at each evaluation location is determined using:

$$\bar{E} = \sqrt{\frac{\sum_{i=1}^{N_\mathrm{p}} E_i^2}{N_\mathrm{p}}} \quad \text{or} \quad \bar{H} = \sqrt{\frac{\sum_{i=1}^{N_\mathrm{p}} H_i^2}{N_\mathrm{p}}} \quad \text{or} \quad \bar{S} = \sqrt{\frac{\sum_{i=1}^{N_\mathrm{p}} S_i^2}{N_\mathrm{p}}} \tag{1}$$

where:

$\bar{E}$	is the spatially-averaged electric field at the evaluation location
E_i	is the max value of the electric field strength at the *i*th measurement point
$\bar{H}$	is the spatially-averaged magnetic field strength at the evaluation location
H_i	is the max value of the magnetic field strength at the *i*th measurement point
N_p	is the total number of measurement points for each evaluation location
$\bar{S}$	is the spatially-averaged plane wave equivalent power density at the evaluation location

S_{i} is the plane wave equivalent power density at the *i*th measurement point

Time averaging is applicable since the RF field strength varies over time due to the changing propagation conditions, variations of the transmitter power due to traffic load, variations due to power control or transmitter duty cycle.

1. Code selective measurement method

In code selective measurements the Secondary Synchronization Signal (SSS) of the downlink of the Physical Broadcast Channel (PBCH) is the always-on signalling channel that is required to be identified in order to acquire information for the SS/PBCH beam identity (SS/PBCH block index). Specifically, in order to quantify the power of specific cells, the code selective analyser employed shall be capable of measuring the SSS and decoding the DM-RS signal.

The SSS typically occupies a bandwidth of 1.905 or 3.810 MHz (127 resource elements). The SS/PBCH block contains the Demodulation Reference Signal (DM-RS), which carries information on the cell identity number (0 to 1007) as well as on the SS/PBCH beam identity (SS/PBCH block index) [8]. The subcarrier spacing of the SSS signal can be 15 kHz, 30 kHz, and 60 kHz for carrier frequencies up to 6 GHz and the bandwidth is $127 \cdot \Delta f$ (Δf is the subcarrier spacing of the PBCH block). The SS/PBCH block has a bandwidth of $240 \cdot \Delta f$ (Δf is the subcarrier spacing of the PBCH block) [9].

The code selective measurement shall be performed in close proximity to the 5G NR RBS at a location of spatial maximum by:

- Identifying and decoding all 5G NR cells *i* by measuring the SS/PBCH blocks of index *j* (this corresponds to the PBCH antenna beam) and demodulating the DM-RS signal.
- Measuring the electric field strength (V/m) for every resource element (RE) of cell *i* and SS/PBCH block *j* ($E_{\mathrm{i,j}}^{\mathrm{SSS(RE)}}$). The root sum square of all measured $E_{\mathrm{i,j}}^{\mathrm{SSS(RE)}}$ values to calculate the spatial maximum quadratic sum of the SSS electric field strength per resource element (RE) of all SS/PBCH blocks ($E_{\mathrm{i,max}}^{\mathrm{SSS(RE)}}$), given as follows:

$$E_{\mathrm{i,max}}^{\mathrm{SSS(RE)}} = \max\left(\sqrt{\sum_{\mathrm{j}} \left(E_{\mathrm{i,j}}^{\mathrm{SSS(RE)}}\right)^2}\right) \tag{2}$$

where:

$E_{\mathrm{i,max}}^{\mathrm{SSS(RE)}}$ is the spatial maximum quadratic sum of the SSS electric field strength per RE) of all SS/PBCH blocks ($\mathrm{Vm^{-1}}$)

$E_{\mathrm{i,j}}^{\mathrm{SSS(RE)}}$ is the electric field strength ($\mathrm{V\ m^{-1}}$) for every resource element of cell *i* and SS/PBCH block *j* ($\mathrm{Vm^{-1}}$)

2. **Frequency selective measurement method**

In Frequency selective evaluations the measurements are based on the SSS signals and for this purpose a minimum resolution bandwidth of the SSS bandwidth ($127\cdot\Delta f$) and a maximum hold-function are required. The subcarrier spacing of the SSS signal can be 15 kHz, 30 kHz, and 60 kHz for carrier frequencies up to 6 GHz and the bandwidth is $127\cdot\Delta f$ (Δf is the subcarrier spacing of the PBCH block).

The measuring device must be set to the centre frequency of the SSS signal. The resolution bandwidth (RBW) shall be appropriately set to cover the SSS signal bandwidth and sweep time = 0.

A similar method has already been proposed for LTE in IEC 62232 [1]. Several preconditions apply to this method:

- The resource element (RE) outside the SS/PBCH blocks are never transmitted with a higher power and a higher antenna gain due to beam forming compared to the nonzero resource elements used in SS/PBCH blocks [10].
- All nonzero resource elements used in SS/PBCH blocks are transmitted with a constant power and a constant antenna gain due to beam forming [10].

2.1.2 Extrapolation from RF field strength to required assessment condition

Extrapolation is applicable to exposure results when the evaluation has been performed at RF power levels lower than the maximum RF transmitted power. To extrapolate time variant signals to the maximum possible output power conditions, a time invariant component of the signal shall be evaluated. The ratio between maximum possible signals and the time invariant component of the signal shall be determined based on knowledge of the technology and the specific RBS configuration. For 5G NR RF in-situ measurements extrapolation can be used to determine the maximum power density or field strength values from the measurement of technology-specific pilot channels (time invariant signals). For 5G NR these are PSS and the SSS of the SS/PBCH block.

Note: If it is not possible to isolate the RF field strength from the time invariant part of the signal (e.g. pilot channels), then an approach which overestimates the maximum RF field strength shall apply. It shall be based on the established ratio and assume that the evaluated levels (E_{eval}) are only derived from the invariant part of the signal. Note that this is a limiting part that leads to overestimation in 5G technologies and a reason for the update of EN 62232.

The extrapolation process shall be performed in the following steps:

- Establish the values of the parameters which define the RBS configuration as evaluated and the RBS configuration to be assessed. If required, relevant criteria to define the potential maximum RF field strength case.
- Establish the case-specific extrapolation factor F_{ext} using all relevant parameters.
- Determine the RF field strength for the assessment configuration by applying the extrapolation factor F_{ext} to the evaluated RF field strength as follows:

$$E_{\mathrm{asmt}} = E_{\mathrm{eval}} \times \sqrt{F_{\mathrm{ext}}} \tag{3}$$

where:

E_{asmt}	is the assessment electric field strength ($\mathrm{Vm^{-1}}$)
E_{eval}	is the evaluated electric field strength ($\mathrm{Vm^{-1}}$)

The extrapolation is dependent whether a frequency or code selective evaluation method is applied.

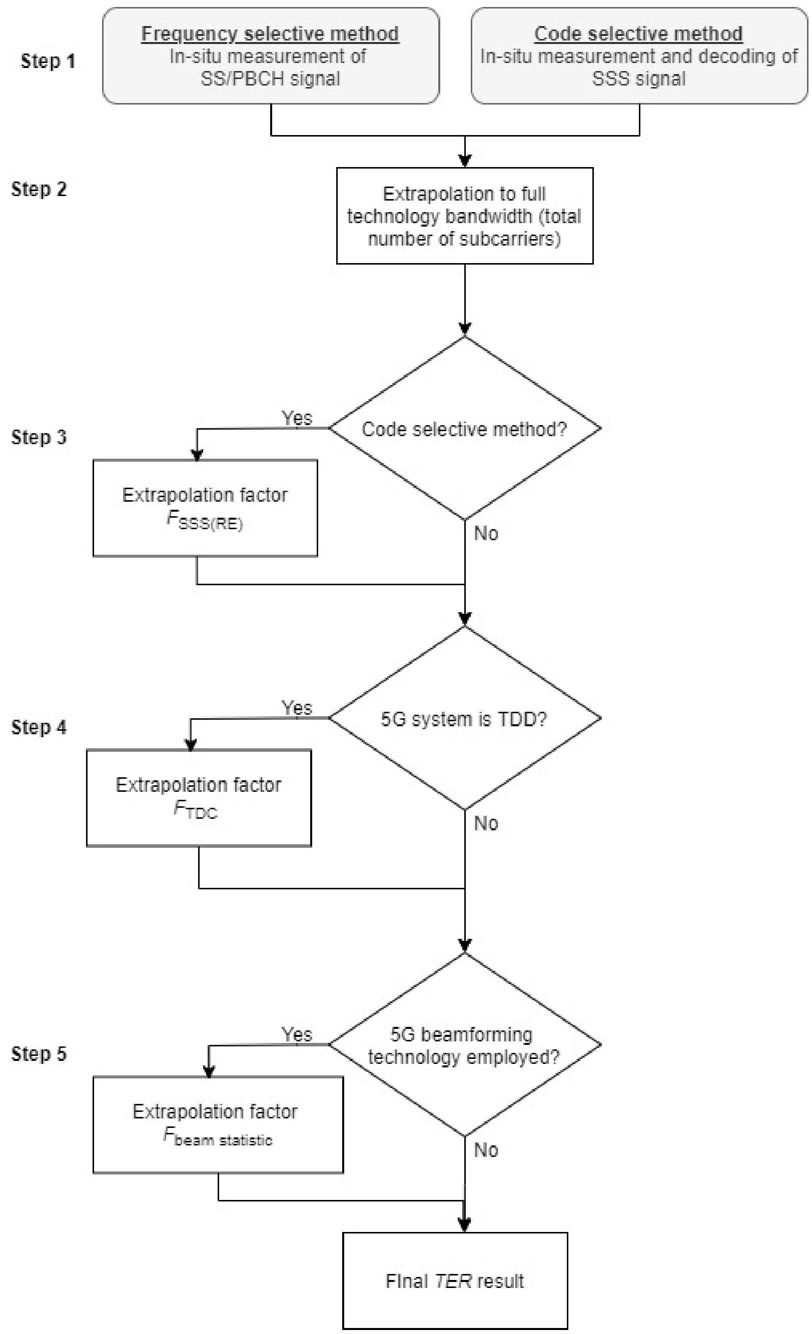

Figure 6. Flowchart of EMF measurement in the vicinity of 5G NR base stations.

- **Code selective extrapolations:**

Extrapolation of the measured and decoded maximum electric field strength of all SSS signals of the investigated cell and formed beams ($E_{\mathrm{i,max}}^{\mathrm{SSS(RE)}}$) shall be performed by considering the actual effective radiative power (ERP), a technology duty cycle (TDC) downlink factor and a beam statistical factor:

$$E_{\mathrm{i,ext}} = E_{\mathrm{i,max}}^{\mathrm{SSS(RE)}} \times F_{\mathrm{i,ext}} \tag{4}$$

$$F_{\mathrm{i,ext}} = F_{\mathrm{i,SSS(RE)}} \times F_{i,\mathrm{TDD}} \times F_{\mathrm{i,beam\ statistic}} \tag{5}$$

where:

$E_{\mathrm{i,ext}}$	is the extrapolated value of the electric field strength for cell *i* ($\mathrm{Vm^{-1}}$)
$E_{\mathrm{i,max}}^{\mathrm{SSS(RE)}}$	is the spatial maximum quadratic sum of the SSS electric field strength per RE) of all SS/PBCH blocks of cell *i* considering all formed beams ($\mathrm{Vm^{-1}}$)
$F_{\mathrm{i,ext}}$	is the extrapolation factor
$F_{i,\mathrm{SSS(RE)}}$	is the SSS (RE) extrapolation factor for cell i
$F_{i,\mathrm{TDC}}$	is the TDC utilization extrapolation factor for cell i
$F_{\mathrm{i,beam\ statistic}}$	is the beamforming statistic extrapolation factor for cell *i*

- **Frequency Selective extrapolations:**

Extrapolation of the measured maximum electric field strength shall be performed by considering a statistical factor to account for the fact that in frequency selective mode the SSS beams cannot be all measured and therefore a factor is required for the quadratic addition of signals from different SS/PBCH beams, a TDC downlink factor and a beam statistical factor:

$$E_{\mathrm{i,ext}} = E_{\mathrm{i,measured\ max}} \times \sqrt{\frac{1}{127}} \times F_{\mathrm{i,ext}} \tag{6}$$

$$F_{\mathrm{i,ext}} = F_{\mathrm{i,SSS(RE)}} \times F_{i,\mathrm{TDC}} \times F_{\mathrm{i,beam\ statistic}} \tag{7}$$

where:

$E_{\mathrm{i,ext}}$	is the extrapolated value of the electric field strength for cell *i* ($\mathrm{Vm^{-1}}$)
$E_{\mathrm{i,measured\ max}}$	is the spatial maximum value of the electric field strength measured over the whole measuring SSS bandwidth ($\mathrm{Vm^{-1}}$)
$\sqrt{1/127}$	is the reduction factor to obtain the field strength per resource element

$F_{\mathrm{i,FSM}}$	is the extrapolation factor for the Frequency Selective Method (FSM) given as √2 if the cell i has more than one SS/PBCH beam and as 1 if the cell i has only one SS/PBCH beam. This is considered because of the fact that the electric field produced by individual beams cannot be measured and therefore cannot be added
$F_{i,\mathrm{SSS(RE)}}$	is the SSS (RE) extrapolation factor for cell i
$F_{i,\mathrm{TDC}}$	is the TDC utilization extrapolation factor for cell i
$F_{\mathrm{i,beam\ statistic}}$	is the beamforming statistic extrapolation factor for cell *i*

<u>Extrapolation Factors Explanation</u>

Extrapolation Factor$F_{\mathbf{i,SSS(RE)}}$:

The $F_{\mathrm{i,SSS(RE)}}$ for cell *i* is defined as the ratio of the actual transmitted power (ERP) of the SSS RE (W) to the maximum permitted power (ERP) without any reduction.

$$F_{\mathrm{i,SSS(RE)}} = \sqrt{\frac{P_{\mathrm{i,permitted}}}{P_{\mathrm{i,SSS(RE)}}}} \quad (8)$$

where:

$F_{i,\mathrm{SSS(RE)}}$	is the SSS (RE) extrapolation factor for cell i
$P_{\mathrm{i,permitted}}$	is the maximum permitted power (ERP) of the signal of all antenna ports of cell i (W)
$P_{\mathrm{i,SSS(RE)}}$	is the actual maximum effective radiated power (ERP) per RE of the SSS of the SS/PBCH block of cell i (W). It corresponds to the sum of the maximum actual effective radiated power of all the decoded SSS beams for cell *i*. For each cell the SS/PBCH blocks can be transmitted on up to 4, or 8 different SS/PBCH beams.

Typically, information about the $P_{\mathrm{i,permitted}}$ and $P_{\mathrm{i,SSS(RE)}}$ is provided by the network operator.

Extrapolation Factor $F_{i,\mathbf{TDC}}$:

The $F_{i,\mathrm{TDC}}$ for cell *i* is defined as the is the ratio of the maximum downlink time within a frame to the total frame length [8]. The factor is employed as follows:

For TDD	$F_{i,\mathrm{TDC}} = \sqrt{\text{Downlink Ratio}}$
For TDD with unknown downlink ratio	$F_{i,\mathrm{TDC}} = 1$
For FDD	$F_{i,\mathrm{TDC}} = 1$

The downlink ratio denoted the maximum ratio of the downlink transmission time in a time interval.

Typically, information about the division duplex mode is provided by network operators.

Extrapolation factor $F_{\mathrm{i,beam\ statistic}}$:

In 5G NR the signalling is not transmitted from the same MIMO antennas and therefore on the same beams as traffic, and for this reason the $F_{\mathrm{i,beam\ statistic}}$ for cell i is considered in order to account for the in traffic and utilization from adaptive TDD antennas. Several studies propose that a 95th percentile exposure can be derived from the maximum theoretical exposure by an agreed-upon reduction factor if a more realistic exposure assessment is required [8]. This parameter is still under study and for this reason the conservative case of $F_{\mathrm{i,beam\ statistic}} = 1$ is recommended.

2.1.3 Uncertainty

The uncertainty is calculated by taking into account all parameters as set out in the ECC/REC/(02)04 [5], and EN 50492 standard [7]. As a minimum, the components listed in Table 4 must be reported. After post-processing the target expanded uncertainty for RF in-situ evaluation shall not exceed 6 dB.

Table 4. Uncertainty table as per the relevant standards.

Components of uncertainty	Reference	Uncertainty in dB	Uncertainty in %	Distribution	Coverage Factor	Standard Uncertainty in %
Calibration uncertainty of the set	Cal. report			Normal		
Temperature influence	Datasheet			Rectangular		
Anisotropy	Cal. report			Uniform		
Perturbation by the environment	Empirical value			Rectangular		
Influence of the body	EN 50492			Rectangular		
Type A uncertainty	Statistical analysis			Normal		
Spatial averaging	EN 50492			Rectangular		

2.1.4 Determination of the Total Exposure Ratio

The total level of exposure (TER) shall be calculated by summing the exposure ration of all emissions. This involves the extrapolated field strength in each band. For the 5G NR this includes the $E_{\mathrm{i,ext}}$. The following formula shall apply:

$$TER = \sum_{i=1}^{N} ER_i \quad (9)$$

where ER_i is the exposure ratio for band *i*.

2.1.5 Reporting

Reporting shall contain at least:

- Description of the measurement site, including the relevant RF sources and the points where measurements have been performed.
- Environmental conditions, time and date, name of entity responsible for the measurement.
- Measurement protocol used, including spatial averaging, time averaging etc.
- Probe and measurement instrument(s) used, including characteristics and calibration details and probe correction factors.
- Measurement results and all information necessary for the interpretation of the in-situ RF exposure evaluation or assessment.
- Uncertainty analysis.

References

[1] International Electrotechnical Commission, Determination of RF field strength and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure; IEC 62232, 2017.

[2] International Commission on Non-Ionizing Radiation Protection (ICNIRP), Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz), Health Physics 74(4):494-522; 1998.

[3] International Commission on Non-Ionizing Radiation Protection (ICNIRP), Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz), Health Physics 118(5):483-524; 2020.

[4] L. Chiaraviglio, A. S. Cacciapuoti, G. di Martino, M. Fiore, M. Montesano, D. Trucchi, and N. Blefari-Melazzi, “Planning 5G networks under emf constraints: State of the art and vision,” IEEE Access, 2018.

[5] ECC/REC/(02)04, Measuring non-ionising electromagnetic radiation (9 kHz – 300 GHz), ECC, 2004.

[6] 1999/519/EC, “Council recommendation of 12th July on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)”, 1999.

[7] International Electrotechnical Commission, Basic standard for the in-situ measurement of electromagnetic field strength related to human exposure in the vicinity of base stations, IEC 50492, 2008.

[8] ETSI TS 138 104, "5G; NR; Base Station (BS) radio transmission and reception (3GPP TS 38.104 version 15.3.0 Release 15)", October 2018.

[9] ETSI TS 138 211, “5G; NR; Physical channels and modulation (3GPP TS 38.211 version 15.2.0 Release 15)”, July 2018.

[10] H. Keller, “On the assessment of human exposure to electromagnetic fields transmitted by 5G NR base stations”, Health Physics, 2019, pp. 541-546.

Appendices

Appendix A – Requested information from network operators

Base Station ID			
Location			
Cell ID			
Antenna			
Main beam direction (azimuth in °)			
Main beam direction (elevation in °)			
Number of PBCH beams			
Service			
Center Frequency (MHz)			
Center Frequency of the PBCH (MHz)			
TDD or FDD mode			
In the case of TDD provide the downlink to uplink ratio			
Numerology of subcarrier bandwidth (kHz)			
Actual ERP of the SSS per resource element $P_i^{SSS(RE)}$ (mW)			
Total permitted ERP $P_{\mathrm{i,permitted}}$ (W)			