International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

Series K
Supplement 16
(07/2022)

SERIES K: PROTECTION AGAINST INTERFERENCE

Electromagnetic field compliance assessments for 5G wireless networks

ITU-T K-series Recommendations – Supplement 16

Supplement 16 to ITU-T K-series Recommendations

Electromagnetic field compliance assessments for 5G wireless networks

Summary

Supplement 16 to the ITU-T K-series Recommendations provides guidance on the radio frequency electromagnetic field (RF-EMF) compliance assessment considerations for the International Mobile Telecommunication system (IMT-2020) wireless networks also known as the fifth Generation of wireless networks (5G). Given that the 5G technical standards have just been finalized and commercial 5G networks are not due to be launched before 2019-2020, the first version of this Supplement is to mainly address the computational assessment options and the assessments of trial networks.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T K Suppl. 16	2018-09-21	5	11.1002/1000/13795
2.0	ITU-T K Suppl. 16	2019-05-22	5	11.1002/1000/13938
3.0	ITU-T K Suppl. 16	2022-07-01	5	11.1002/1000/15079

Keywords

5G, computational methods, RF-EMF compliance.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

This is an informative ITU-T publication. Mandatory provisions, such as those found in ITU-T Recommendations, are outside the scope of this publication. This publication should only be referenced bibliographically in ITU-T Recommendations.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this publication may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the publication development process.

As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents/software copyrights, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the appropriate ITU-T databases available via the ITU-T website at http://www.itu.int/ITU-T/ipr/.

Table of Contents

Supplement 16 to ITU-T K-series Recommendations

Electromagnetic field compliance assessments for 5G wireless networks

1 Scope

This Supplement 16 to ITU-T K-series provides guidance on the radio frequency electromagnetic field (RF-EMF) compliance assessment considerations for 5th Generation (5G) wireless networks, including 5G base stations (BS) located at existing wireless network facilities.

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.70]	Recommendation ITU-T K.70 (2020), *Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations*.
[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*.
[ITU-T K-Suppl.9]	ITU-T K-series Recommendations – Supplement 9 (2019), *5G technology and human exposure to radiofrequency electromagnetic fields*.
[ITU-R P.1238]	Recommendation ITU-R P.1238 (2021), *Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz.*
[IEC/IEEE 62209-1528]	IEC/IEEE 62209-1528:2020, *Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-worn wireless communication devices – Human models, instrumentation and procedures (Frequency range of 4 MHz to 10 GHz).*
[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*.
[IEC/IEEE 63195-1]	IEC/IEEE 63195-1:2022, *Assessment of power density of human exposure to radio frequency fields from wireless devices in close proximity to the head and body (frequency range of 6 GHz to 300 GHz) – Part 1: Measurement procedure.*
[IEC/IEEE 63195-2]	IEC/IEEE 63195-2:2022, *Assessment of power density of human exposure to radio frequency fields from wireless devices in close proximity to the head and body (frequency range of 6 GHz to 300 GHz) – Part 2: Computational procedure.*

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 actual maximum power [b-IEC TR 62669]: Value of transmitted power reached during operations at a given percentile of the cumulative distribution function (CDF) of a statistical evaluation taking into account the averaging time tavg and the variation of the base station (BS) load for the whole duration of the statistical evaluation.

NOTE – For a given base station (BS) site, the actual maximum transmitted power or equivalent isotropically radiated power (EIRP) of radio frequency (RF) exposure or RF compliance boundary is defined as the default value for a 95th percentile when using computational methods or for a 100th percentile when using measurement methods. When another percentile is used for this BS site, the recommended notation is to add the "-*pxx*" suffix to the assessed quantity, where xx is the percentile used for the statistical evaluation. For example, P_{TXA}-p99 is the actual maximum transmitted power based on statistical approaches using the 99th percentile.

3.1.2 antenna: [ITU-T K.70].

3.1.3 averaging time [b-IEC TR 62669]: Appropriate time over which exposure is averaged for purposes of determining compliance.

3.1.4 base station: [ITU-T K.100].

3.1.5 basic restrictions: [ITU-T K.70].

3.1.6 compliance boundary: [ITU-T K.100].

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

3.1.8 equivalent isotropically radiated power (EIRP): [ITU-T K.100].

3.1.9 exposure: [ITU-T K.52].

3.1.10 exposure level: [ITU-T K.52].

3.1.11 exposure limits: [ITU-T K.70].

3.1.12 general public: [ITU-T K.52].

3.1.13 massive MIMO [b-IEC TR 62669]: Method used for multiplying the capacity of a radio link in a multicarrier cellular network in which a base station (BS) j is equipped with Mj >> 1 antennas, to achieve channel hardening and communicates with Kj single-antenna UEs simultaneously on each time/frequency sample, with antenna-UE ratio Mj/Kj > 1.

3.1.14 power density (S): [ITU-T K.52].

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

3.1.16 rated maximum power [b-IEC TR 62669]: Value of transmitted power as declared by the manufacturer.

3.1.17 specific absorption rate (SAR): [ITU-T K.52].

3.1.18 transmitter: [ITU-T K.70].

3.1.19 transmitted power [b-IEC TR 62669]: Total power transmitted by a base station under test during the transmitter ON period assessed either at the antenna input port(s) for passive antennas or as the total radiated power for base stations with built-in antennas.

3.2 Terms defined in this Supplement

None.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

5G 5th Generation of Wireless Networks

APD Absorbed Power Density

BS Base Station

EMF Electromagnetic Field

EIRP Equivalent Isotropically Radiated Power

FDD Frequency Division Duplex

ICNIRP International Commission on Non-Ionizing Radiation Protection

IMT-2020 International Mobile Telecommunication system

LTE Long Term Evolution

MIMO Multiple Input Multiple Output

mMIMO massive MIMO

mmWave millimetre-wave

NR New Radio

RAN Radio Access Network

RF Radio Frequency

SAR Specific Absorption Rate

TDD Time Division Duplex

WRC World Radiocommunication Conferences

5 Overview of 5G networks

5G is the 5th generation of wireless networks, a significant evolution of the 4G long term evolution (LTE) networks. 5G has been designed to meet the very large growth in data and connectivity of today's modern society, the Internet of things (IoT) with billions of connected devices, and tomorrow's innovations.

The 5G wireless network that enables high-speed data transmission with ultra-low latency is the key infrastructure for future technology that will lead the fourth or next industrial revolution such as artificial intelligence, autonomous vehicle, big data, and the cloud.

5G will initially operate in conjunction with existing 4G networks before evolving to fully standalone networks in subsequent releases and coverage expansions.

General information on 5G wireless networks can be found in [ITU-T K-Suppl.9].

6 5G spectrum

5G will use additional spectrum predominately in the 3-86 GHz range to significantly add more capacity compared to the current mobile technologies. The additional spectrum and greater capacity will enable more users, more data, and faster connections. It is also expected that there will be future reuse of existing low band spectrum for 5G as legacy networks decline in usage and to support future use cases.

The increased spectrum also includes the millimetre-wave (mmWave) bands. The mmWave frequencies provide localised coverage as they mainly operate over a short line of sight distances.

Figure 1 shows the existing and new spectrum that will be used for 5G mobile communications.

– **Low band (below 1 GHz)** – providing widespread coverage across urban, suburban, and rural areas and supporting IoT for low data rate applications.

– **Medium band (1-6 GHz)** – providing good coverage and high speeds and, including the expected initial 5G range of 3.3-3.8 GHz which has been identified as the most likely band for launching 5G globally.

– **High band (above 6 GHz)** – providing ultra-high broadband speeds for advanced mobile broadband applications, and which is most suitable for applications in dense traffic hotspots. The 26-28 GHz band has been identified by some administrations for future 5G applications.

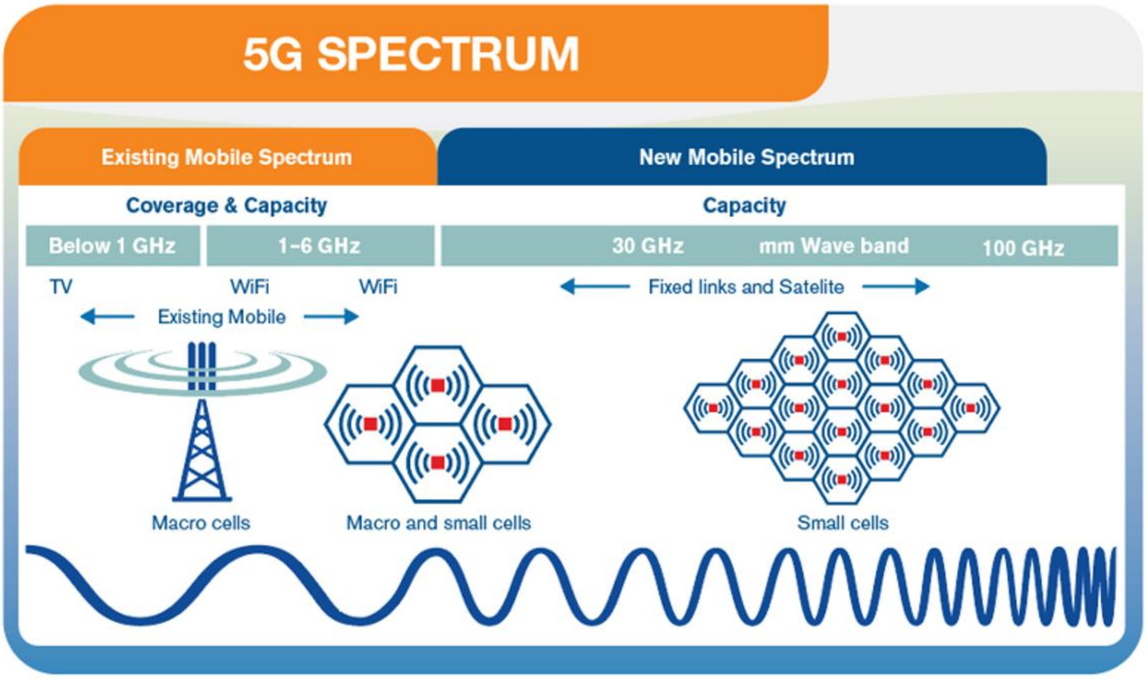


Figure 1 – Existing and new spectrum to be used for 5G mobile communication services [b-EmfExpl]

Spectrum for mobile telecommunication services including 5G is determined by the World Radiocommunication Conferences (WRC) which are held every three to four years. It is the job of the WRC to review, and, if necessary, revise the radio regulations, the international treaty governing the use of the radio-frequency spectrum and the geostationary-satellite and non-geostationary-satellite orbits. Revisions are made based on an agenda determined by the International Telecommunication Union (ITU) Council, which takes into account proposals made by previous WRC. The WRC designates frequencies for use by International Mobile Telecommunication system (IMT-2020).

The 5G standards are expected to support both frequency division duplex (FDD) and time division duplex (TDD). Research is also underway on full duplex systems for 5G to transmit and receive simultaneously on the same channel. Full duplex effectively doubles the spectrum efficiency.

7 How 5G wireless networks work

Most operators will initially integrate 5G networks with existing 4G networks to provide a continuous connection. In Figure 2, an illustration of the 5G network architecture is provided. More information can be found in [ITU-T K-Suppl.9].

A wireless network has two main components, the 'radio access network' (RAN) and the 'core network'.

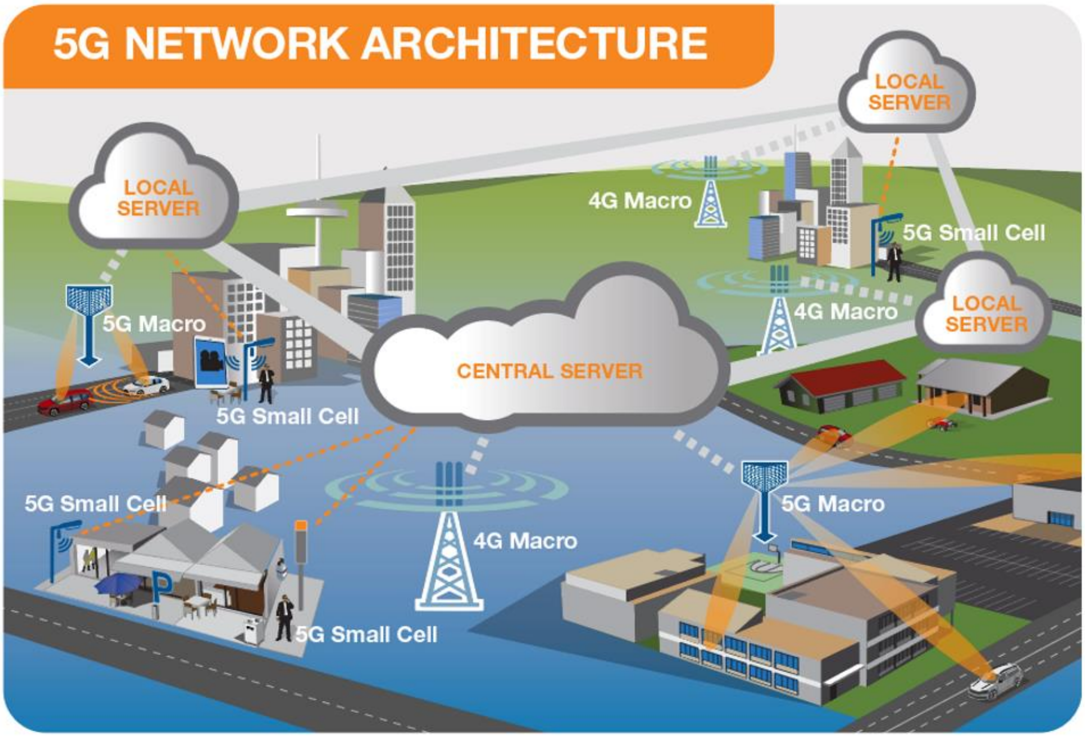


Figure 2 – Schematic illustration of the architecture for 5G mobile communication networks [b-EmfExpl]

7.1 The radio access network

The radio access network (RAN) consists of various types of facilities including small cells, towers, masts, street furniture and dedicated in-building and home systems that connect mobile users and wireless devices to the main core network.

Small cells will be a significant feature of 5G networks, particularly at the new mmWave frequencies where the connection range is very short. To provide a continuous connection, small cells will be distributed in clusters depending on where users require connection, and this will complement the macro network.

5G macro cells will use antennas that have multiple elements to send and receive more data simultaneously and cater to multiple connections. The benefit to users is that more people can simultaneously connect to the network and maintain high throughput. Antenna arrays for 5G are often referred to as 'massive multiple input multiple output (MIMO)' (mMIMO) due to a large number of multiple elements.

7.2 5G massive MIMO antenna configurations

5G massive MIMO (mMIMO) antennas are similar to existing 3G and 4G base station antennas, however, with a much higher frequency. The individual element size is smaller allowing more elements (for example 64 or 512). Figure 3 shows the difference between conventional sector antennas and the mMIMO antennas used in the 5G networks.

Beam steering and beamforming is a technology that allows the mMIMO base station antennas to direct the radio signal to the users and devices rather than in all directions. The beam steering technology uses advanced signal processing algorithms to determine the best path for the radio signal to reach the user. This increases the efficiency as it reduces the interference (i.e., unwanted radio signals). Figure 4 illustrates how beam steering and beamforming works in a 5G network.

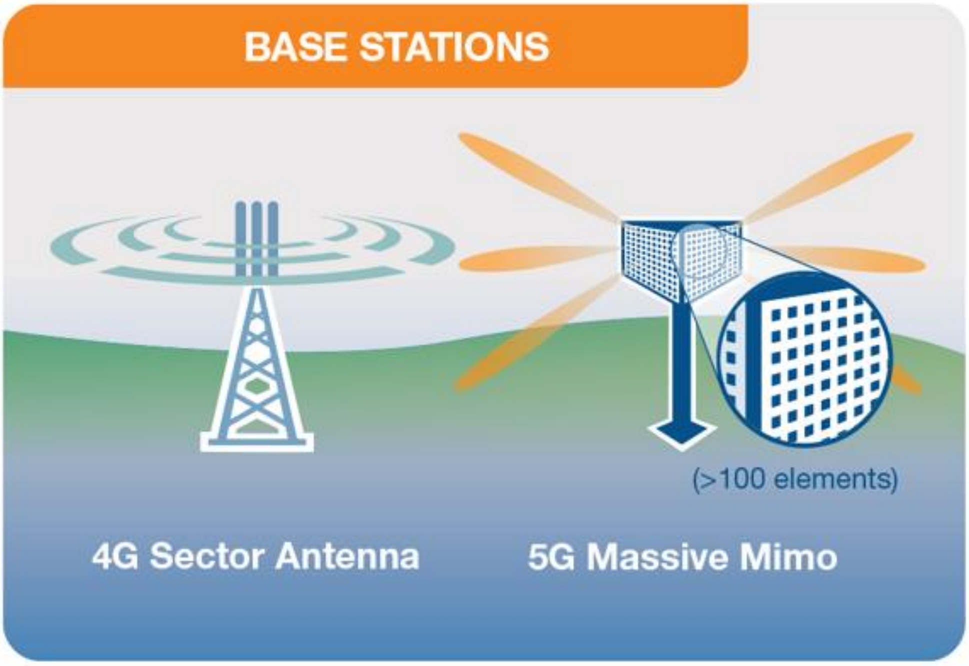


Figure 3 – 4G base station with sector antennas and 5G base station with multi-element Massive MIMO antenna array [b-EmfExpl]

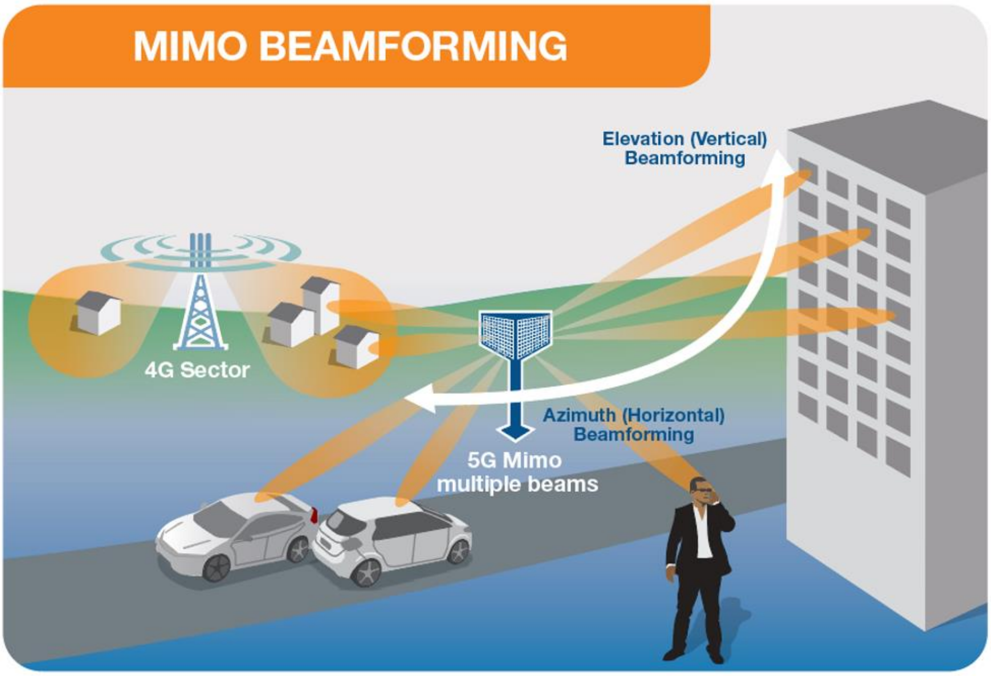


Figure 4 – Massive MIMO beamforming and beam steering in a 5G network [b-EmfExpl]

7.3 The core network

The core network is the mobile exchange and data network that manages the mobile voice, data, and the internet connections. For 5G, the core network is being redesigned to better integrate with the internet and cloud-based services and includes distributed servers across the network improving the response times (reducing latency).

Many of the advanced features of 5G, including network virtualization and network slicing for different applications and services, will be managed in the core network.

7.4 5G working with 4G

In non-standalone deployments (i.e., 5G working jointly with 4G), when a 5G connection is established, the user equipment (or device) connects to the 4G network to provide control signalling and to the 5G network provide a fast data connection by adding to the existing 4G carriage.

Where there is limited 5G coverage, the data is carried on the 4G network providing a continuous connection. Essentially with this design, the 5G network is complementing the existing 4G network. Figure 5 illustrates how the 5G integration with 4G networks will work.

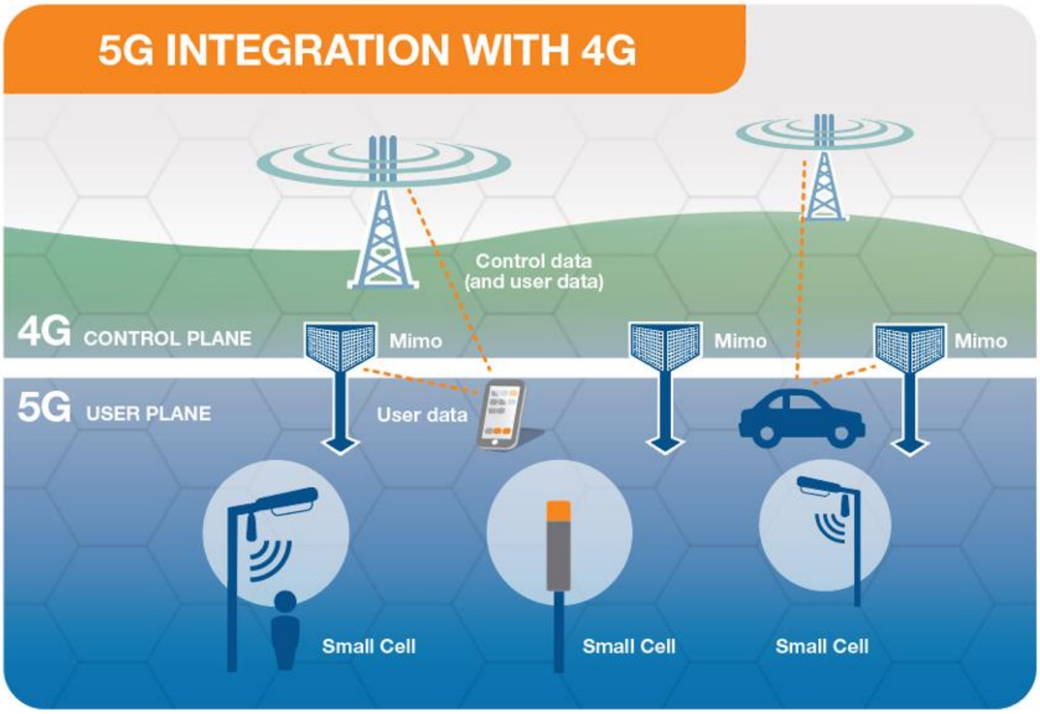


Figure 5 – Illustration of how the 5G networks will initially be integrated with existing 4G networks [b-EmfExpl]

8 5G and radio frequency electromagnetic field (RF-EMF) exposure

8.1 5G, RF-EMF and health

The radio frequency bands allocated for use by 5G including the mmWave frequencies have been used by other radio frequency applications such as microwave communication, satellite, and radar for decades. 5G wireless networks are designed to be very efficient. This means that both the network and device transmission power will be low, which means that levels of RF-EMF in a 5G environment are within the International Commission on Non-Ionizing Radiation Protection (ICNIRP) exposure limits.

The World Health Organization (WHO), the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) of the European Union, and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) concluded that the exposure related to wireless networks and their use does not lead to adverse effects for public health if it is below the limits recommended by the ICNIRP. Research on possible human health effects of the RF-EMF exposure to mmWave frequencies goes back many decades and is continuing. In terms of research specifically on the 5G frequency range, the EMF portal database [b-EMF] lists approximately 350 studies on mmWave RF-EMF health related research. Extensive research on mmWave and health has been conducted on radar, microwave, and military applications.

Tissue heating remains the only recognised and substantiated hazard of exposure to mmWave frequencies based on scientific research to date.

However, despite much research and communication efforts to resolve it, there is still some public concern about the possible harmfulness of RF-EMFs from mobile communication equipments. In addition, there will be numerous new 5G base stations around the areas where people live and work, which may lead to additional public concern. It is very important to properly address these concerns, and ensure the efficiency of wireless networks and maintain low RF-EMF levels through the evolution of the current networks and the expansion of 5G wireless networks, which constitute the key infrastructure that will enable the entry into the smart information society.

8.2 RF-EMF exposure limits

Comprehensive international guidelines exist for governing exposure to radio waves used at 5G frequencies. The limits have been established by independent scientific organizations, such as the ICNIRP and which include substantial margins of safety to protect all populations.

These guidelines have been widely adopted in standards and regulations around the world, and also endorsed by the WHO. Where national limits do not exist, or if they do not cover the frequencies of interest, then the ICNIRP limits should be used [ITU-T K.91].

9 RF-EMF exposure compliance assessments

The International Electrotechnical Commission (IEC) technical committee 106 is responsible for preparing international standards on measurement and calculation methods to assess human exposure to electric, magnetic, and electromagnetic fields. The IEC and ICNIRP have agreed on the sharing of responsibilities for the EMF standards. EMF exposure limit guidelines are developed by the ICNIRP, and the EMF exposure assessment standards are developed by IEC and ITU.

A list of the relevant IEC standards is available from the IEC TC 106 website.

9.1 5G RF-EMF assessment standards

9.1.1 Base stations and wireless networks

[IEC 62232] specifies the assessment methods for base stations and wireless networks. It covers a frequency range of up to 100 GHz and includes methodology applicable for 5G.

IEC Technical Report [b-IEC TR 62669] provides case studies for the implementation of [IEC 62232], including 5G base stations, and describes the general guidelines for the compliance of base stations using mMIMO. [b-IEC TR 62669] also includes case studies for the assessment of standalone and shared 3G, 4G and 5G base stations, and small cells.

9.1.2 Mobile devices

IEC has developed a Technical Report [b-IEC TR 63170] that describes the state-of-the-art measurement techniques and test approaches for evaluating the local and spatial-average incident power density of wireless devices operating in close proximity of the users at 6 GHz to 100 GHz. As a follow-up, new standards were developed on computation methods [IEC/IEEE 63195-2] and measurement methods [IEC/IEEE 63195-1] covering from 6 GHz to 300 GHz. The methods in these standards are also intended to be included in the next edition of [IEC 62232]. For specific absorption rate (SAR) assessments of 5G devices using frequency bands up to 10 GHz, [IEC/IEEE 62209-1528] is applicable. Absorbed power density (APD) assessment method is also being developed [b-IEC PAS 63446].

9.2 5G wireless network RF-EMF compliance assessment methods

RF-EMF compliance assessments for 5G networks will require careful analysis of the design and configuration of the site to be evaluated, and whether an mMIMO or small cell configuration has been deployed. The purpose of the assessment is typically to determine the size of the RF-EMF compliance boundary (exclusion zone) for the general public and workers around the antennas, and to verify that this zone is not accessible. Alternatively, calculations or measurements may be conducted close to a base station site, in areas that are accessible to the general public, to verify that the RF-EMF exposure levels are below the applicable limits. Guidance on how to perform RF-EMF compliance assessments are provided in [ITU-T K.100] as well as [IEC 62232] and [b-IEC TR 62669].

9.3 Uncertainty considerations for 5G compliance assessments

Providing uncertainty estimates is particularly important when determining compliance with exposure limits.

The assessment of uncertainty relevant for 5G compliance assessments is detailed in [IEC 62232], [ITU-T K.91] and an example of uncertainty estimation including some of the factors listed in [IEC 62232] is described in [b-Kim].

9.4 Determining the actual maximum power for RF-EMF compliance assessments of 5G networks

The advances in wireless network technology for 5G have resulted in wireless networks becoming significantly more efficient and requiring less transmitted power to deliver the same data rates. 5G networks will transmit similar power levels compared to previous mobile technologies. Like current 2G, 3G and 4G networks, 5G base stations will not be designed to operate at maximum power except for very short times in order to handle traffic variations. This means that the transmitted power is averaged over time periods of relevance for RF-EMF exposure assessments, e.g., six minutes, is significantly lower than the rated maximum transmitted power for the equipment.

Consequently, using the rated maximum power will lead to overly conservative RF-EMF exposure values and compliance boundaries, especially in the case of several different technologies and antennas at the site. To address this issue, both [ITU-T K.100] and [IEC 62232] open up the possibility of using the 'actual maximum power', which can be determined from measurements of the base station's real output power, from measurements of a large number of representative base stations in the network, or by using statistical models or network simulations [b-Thors], and [b-Baracca]. The actual maximum power can for example be taken as the 95th percentile value of the obtained power distribution [b-IEC TR 62669].

For EMF exposure assessments of 5G sites using mMIMO, it is important to accurately determine the actual maximum transmitted power. Massive MIMO base stations transmit a number of simultaneous beams to the connected devices. These beams vary rapidly in both time and space, and there will be no transmission in a certain direction at the rated maximum power for long periods of time. [b-IEC TR 62669] provides detailed guidance on how to determine the actual maximum power for mMIMO antennas.

9.5 Transmitted power and RF-EMF exposure from 5G massive MIMO antennas

The configuration of a massive MIMO 5G site will vary depending on the operator network design and implementation of the applicable 3GPP standards. The calculation of the actual maximum transmitted power and the actual maximum EMF exposure from an mMIMO 5G antenna array requires several factors to be considered, including:

– total maximum transmitted power;

– fraction of power used for traffic beams and broadcast / synchronization beams;

– beam steering ranges and half-power beamwidths;

– antenna radiation pattern (envelope of all traffic beams);
– maximum gain for traffic beams and broadcast / synchronization beams;
– number of possible simultaneous traffic beams;
– installation environment;
– distribution of connected devices;
– time division duplex (TDD) or frequency division duplex (FDD).

[b-IEC TR 62669] provides guidance on the methods to determine the actual maximum power for mMIMO base station antennas and includes case studies describing how to assess RF-EMF compliance for a number of typical 5G sites. Given below are two case studies illustrating how EMF compliance assessments of 5G macro and small cell sites may be performed.

9.6 Results of 5G RF-EMF assessments

Around the world, national health agencies, government regulators, academia, test laboratories, mobile operators and manufacturers have conducted extensive testing on commercial and test networks to determine 5G RF-EMF exposure levels.

An interactive map[1] includes the data from multiple stakeholders. Measured levels are for publicly accessible areas, typically at ground level. 5G RF-EMF levels were converted to a percentage of the relevant international [b-ICNIRP] public RF-EMF limit.

The summary shows that:

– international safety and testing standards are in place for all 5G frequencies including millimetre waves;
– measured levels from 5G networks operating in all continents are low, and well below the international safety limits;
– 5G RF-EMF levels are similar to other wireless technologies with little difference between the frequency bands.

The typical maximum measured 5G RF-EMF level across the surveys is about or less than 1% (power density) of the international public limits.

5G networks are designed to use the radio spectrum efficiently and this is evident in the testing. Reduced signalling requirements for 5G and the use of smart antenna systems mean more efficient use of the RF-EMF energy.

10 Case study about RF-EMF compliance assessment of a 5G massive MIMO macro BS site

This case study illustrates a typical 5G new radio (NR) macro base station operating in medium frequency bands around 3.5 GHz, which has an mMIMO array antenna with 64 antenna element sub-arrays and the same number of transmitters and receivers. With this antenna, narrow traffic beams can be steered ±60 degrees in the horizontal direction and ±20 degrees in the vertical direction. Manufacturers of such base station products generally provide antenna radiation pattern data files, which are constructed by combining the patterns for all the possible traffic beams. These antenna files thus give the maximum gain in all possible directions and correspond to the envelope of traffic beams.

In this case study, a 5G rooftop macro site with a 3.5 GHz mMIMO base station was modelled. The base station has a rated maximum transmitted power of 200 W and uses the time division duplex (TDD) with a maximum downlink duty cycle of 0.75 (i.e., the base station transmits only 75% of the time). As a conservative assumption for 5G NR, all of the power was assumed to be used for the

[1] https://www.gsma.com/publicpolicy/emf-and-health/safety-of-5g-networks/5g-emf-surveys

traffic beams, i.e., no power was used for the control channel transmission. Figure 6 shows a drawing of the site with the installed base station, and Table 1 provides data for the assessed product.

The ICNIRP limits [b-ICNIRP 1998] for the general public (10 W/m^2) and workers (50 W/m^2), with an average time of 6 minutes, were applied to determine the three-dimensional compliance boundaries which are used to verify that the RF-EMF exposure is below the limits in the accessible areas.

10.1 RF exposure compliance evaluation process

The evaluation was based on computations using the "synthetic model and ray tracing algorithms" method specified in [IEC 62232] and using the commercial software IXUS (Alphawave, South Africa). A model of the antenna was created based on the traffic beam envelope data files and this model was used with the computation software. Contributions from other ambient sources were considered insignificant.

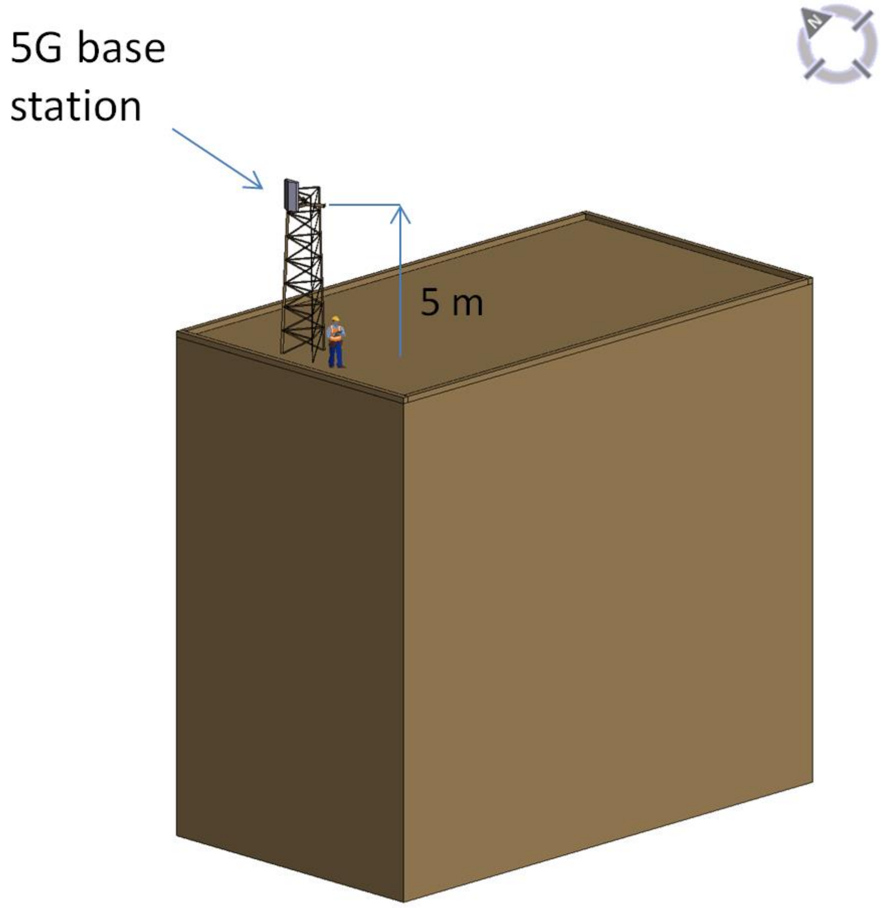


Figure 6 – Drawing of the assessed 5G macro site with a 3.5 GHz massive MIMO base station. The lower part of the antenna is at 5-metre height above the rooftop [b-EmfExpl]

Table 1 – Data for the assessed base station

Product name	5G NR base station (TDD)
Operating frequency band	3400 MHz to 3600 MHz
Antenna array configuration	(8 × 8) array of cross-polarized antennas (128 antenna elements) 64 (2 × 1) sub-arrays (32 per polarization)
Tx / Rx configuration	64T / 64R

Table 1 – Data for the assessed base station

Product name	5G NR base station (TDD)
Maximum gain	23.7 dBi
Maximum scan range in the horizontal plane	±60°
Maximum scan range in the vertical plane	±20°
Downtilt	3°
TDD duty cycle	75%
Total rated maximum power	200 W
Maximum EIRP	76.7 dBm

10.2 RF exposure compliance evaluation

The actual maximum transmitted power of the array antenna was determined using the methodology described in [b-IEC TR 62669] and the results from the statistical modelling studies referenced in that technical report. There are three main factors impacting the actual maximum power that contributes to the time-averaged RF-EMF exposure from mMIMO antennas: 1) Time division duplexing (technology duty cycle), 2) Scheduling time and spatial distribution of served users, and 3) BS utilization (traffic load). The second factor can be expressed as a 'power reduction factor' and takes into account that the power (or EIRP) is spread in different directions during the 6-minute averaging time. Figure 7 (taken from [b-IEC TR 62669]) shows the cumulative distribution function (CDF) of the power reduction factor for an 8 × 8 mMIMO antenna for both rural and urban installation scenarios, determined using statistical methods. The 95th percentile value for rural environments, i.e., 0.32, was selected for this case study.

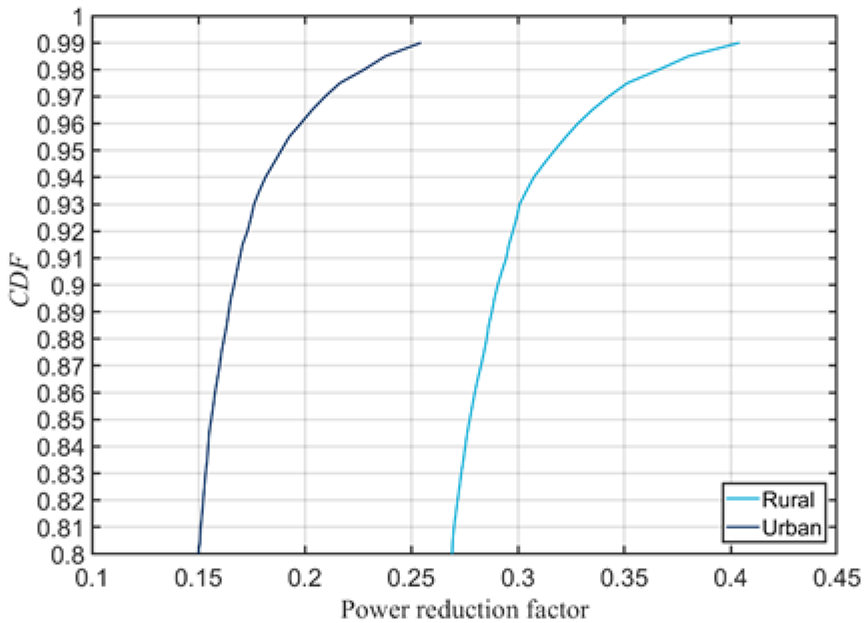


Figure 7 – Cumulative distribution functions (CDF) of the power reduction factor for rural and urban installation scenarios of an 8 × 8 massive MIMO antenna array [b-IEC TR 62669]

With a technology duty cycle of 0.75, and a power reduction factor of 0.32, the actual maximum power (averaged over 6 minutes) is 25% (0.75 × 0.32) of the rated maximum power. Consequently, an actual maximum power of 50 watt (25% of 200 W) was used for the 5G site assessment.

The applied power reduction factor of 0.32 is applicable for 8 × 8 antenna arrays and for realistic device distributions in rural environments. The results can be expected to be conservative for urban installations, where the user device distribution will lead to a smaller power reduction factor (95th percentile value less than 0.2, as seen in Figure 7). In addition, a BS utilization (traffic load) close to 100% was assumed, which adds to the conservativeness of the computations since typical traffic loads are around 50% or less.

Figures 8 and 9 show the resulting compliance boundaries (exclusion zones) for the general public and workers at the evaluated 5G NR mMIMO rooftop site and for the actual maximum power of 50 watt. The minimum vertical distance from the rooftop to the lower edge of the compliance boundary is 2.8 metres for the general public and 4.2 metres for workers, and is larger on the roof, so if the rooftop is accessible for both these groups, the RF-EMF exposure is below the relevant limits. In front of the base station antenna, the general public RF-EMF compliance distance is 9.6 metres. Assuming that the distance to the adjacent buildings and areas accessible to the general public is larger than this, the 5G site is compliant with the relevant limits.

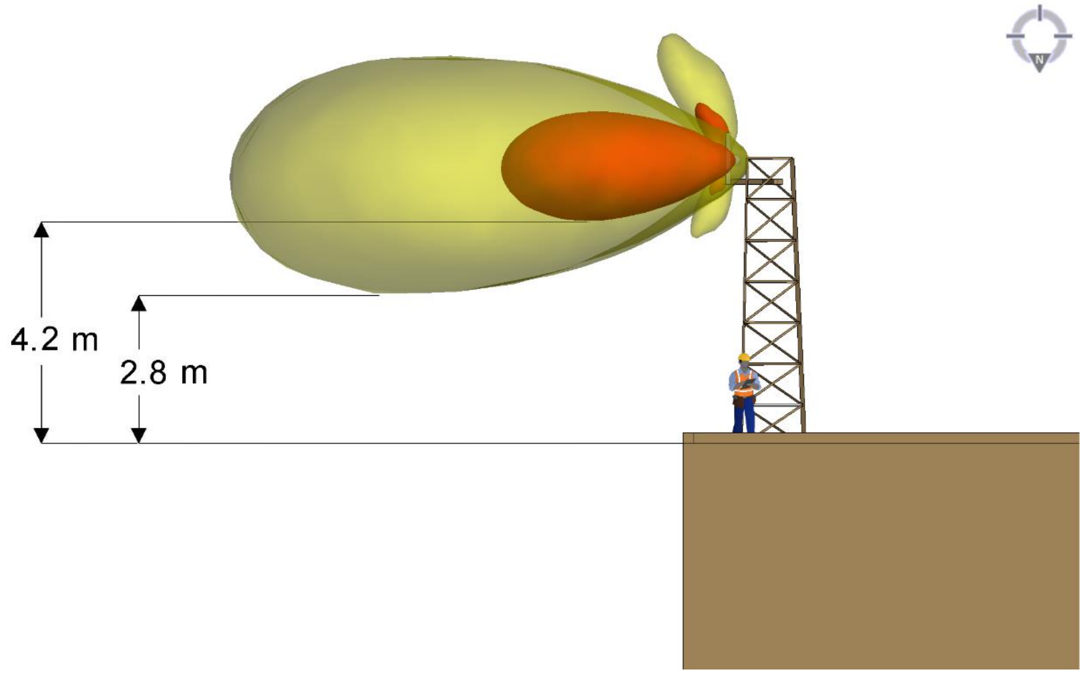


Figure 8 – Vertical view of the computed compliance boundaries for the general public (yellow) and workers (red) around the 5G 3.5 GHz base station installed on a building rooftop. Indicated are the vertical distances from the rooftop to the lowest point of the compliance boundaries [b-EmfExpl]

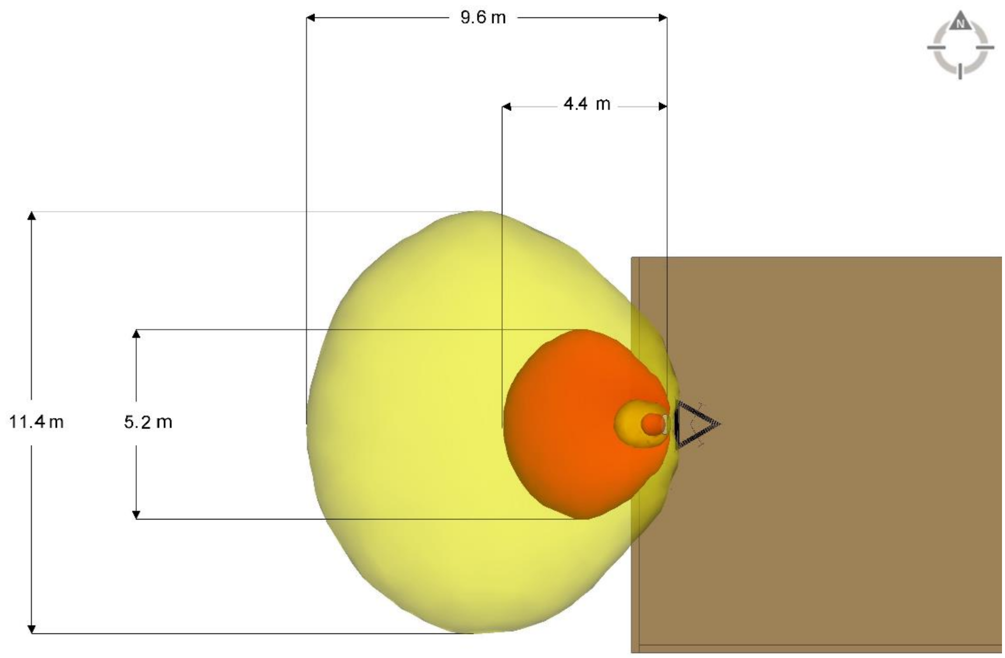


Figure 9 – Horizontal view of the computed compliance boundaries for the general public (yellow) and workers (red) around the 5G 3.5 GHz base station installed on a building rooftop. Indicated are the lengths and widths of the compliance boundaries [b-EmfExpl]

11 Case study about RF-EMF compliance assessment of a 5G small cell site

This case study illustrates a product installation compliance assessment for a 5G small cell operating in a time division duplex (TDD) with a massive MIMO antenna transmitting at 27 GHz installed at an indoor 5G test and innovation laboratory in Southport, Australia. Figure 10 shows the environment in which the 5G small cell was installed.

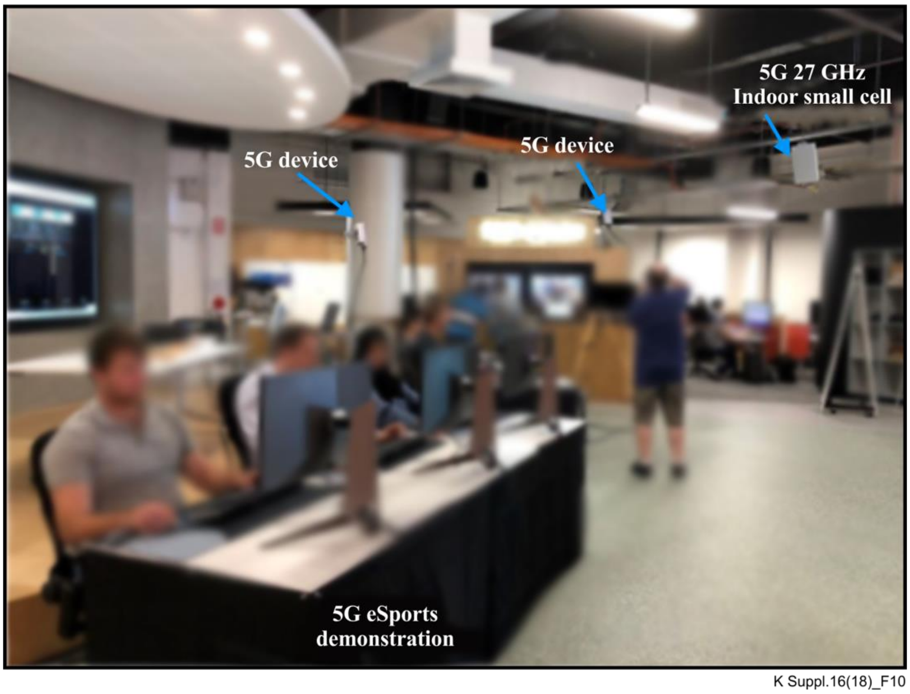


Figure 10 – Picture of the assessed indoor 5G small cell at the Southport 5G innovation laboratory [b-EmfExpl]

11.1 Small cell configuration

The small cell antenna is installed 3 m above ground level and has two power configurations:

– power configuration 1: full power test mode (48 dBm EIRP);

– power configuration 2: demonstration mode (38 dBm EIRP).

The demonstration mode is the installed configuration for the 5G indoor trials and demonstrations and includes a minimum of 10 dB attenuation [ITU-R P.1238] due to the small indoor coverage area, good quality signal, and the requirement to not overload the system.

Depending on the ongoing trials in the laboratory, the TDD factor varied from 50% to 96%. For the compliance assessment, a TDD factor of 100% was chosen due to the specific laboratory configuration.

11.2 Compliance evaluation process

This product installation compliance assessment follows the procedures as defined in [IEC 62232] and [ITU-T K.100], and specifically the simplified evaluation process described in clause 6.2.4 of [IEC 62232] and clause 7 of [ITU-T K.100]. Table 2 in [IEC 62232] and Table 8-1 in [ITU-T K.100] specify the product installation classes where a simplified evaluation process is applicable based on the ICNIRP general public limits.

11.3 RF exposure compliance evaluation

The indoor small cell installation in the demonstration mode is classed as E10 (<10 W or 40 dBm EIRP) and therefore meets the requirements for the simplified installation. For the E10 class, the simplified installation criteria state: 'The product is installed according to instructions from the manufacturer and/or entity putting into service and the lowest radiating part of the antenna(s) is at a minimum height of 2.2 m above the general public walkway'.

In summary, the indoor small cell is located 3 m above the ground away from public access and operates at a low power level, therefore meeting the simplified assessment requirements of [IEC 62232] and [ITU-T K.100] and no further assessment is required.

The indoor small cell installation in full power test mode is classed as E100 (<100 W or 50 dBm EIRP) and must meet the requirements for the simplified installation under the following conditions:

The product is installed according to the instructions from the manufacturer and complies with the following criteria:

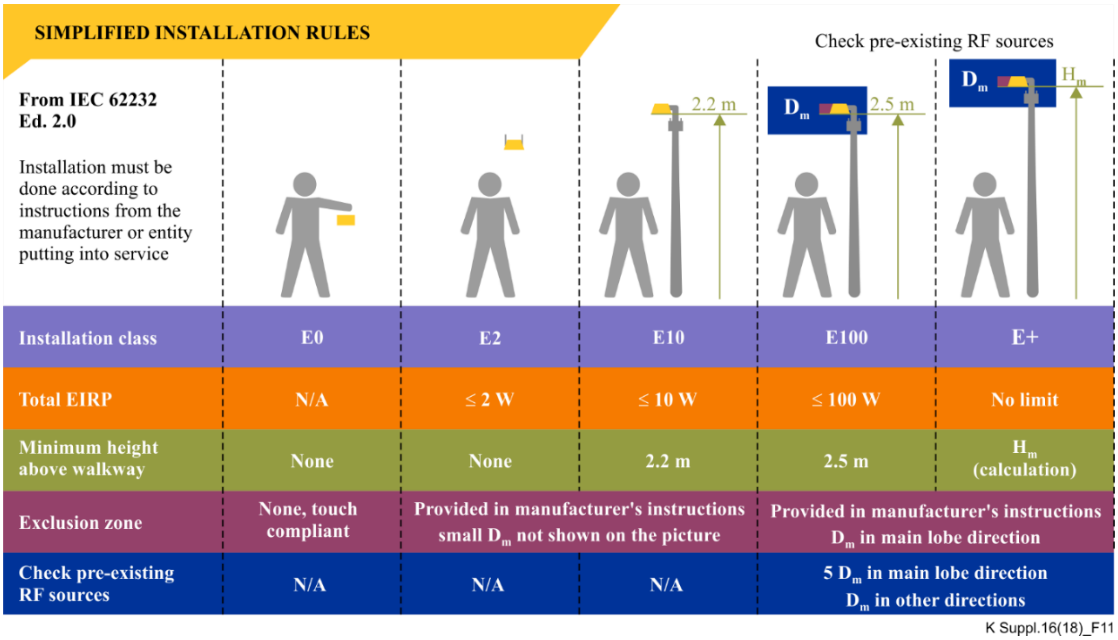
– the lowest radiating part of the antenna(s) is at a minimum height of 2.5 m above the general public walkway;

– the minimum distance to areas accessible to the general public in the main lobe direction is D_m = 0.7 m as provided by the manufacturer.

There are no pre-existing RF sources with EIRP above 10 W installed within a distance of 3.5 metres ($5D_m$) in the main lobe direction (as determined by considering the half power beam width) and within 0.7 meters (D_m) in other directions.

In summary, the indoor small cell antenna is located 3 m above the ground and there is no access to the minimum distance of 0.7 m in the main lobe. There are no pre-existing RF sources with an EIRP above 10 W installed within a distance of 3.5 m ($5D_m$) in the main lobe direction and within 0.7 m (D_m) in other directions. The small cell meets the simplified assessment, and no further assessment is required.

These results confirm the simplified installation rules developed in [IEC 62232] and [ITU-T K.100] that are outlined in Figure 11 from [b-SCF012] and [ITU-T K-Suppl.9].



(Source: Small Cells Forum and GSMA)

Figure 11 – Simplified installation rules

Bibliography

[b-IEC TR 62669] 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.*
<https://webstore.iec.ch/publication/62014>

[b-IEC TR 63170] IEC TR 63170:2018, *Measurement procedure for the evaluation of power density related to human exposure to radio frequency fields from wireless communication devices operating between 6 GHz and 100 GHz.*
<https://webstore.iec.ch/publication/62012>

[b-IEC PAS 63446] IEC PAS 63446 ED1 (2022), *Conversion method of specific absorption rate to absorbed power density for the assessment of human exposure to radio frequency electromagnetic fields from wireless devices in close proximity to the head and body – frequency range of 6 GHz to 10 GHz.*
<https://www.iec.ch/ords/f?p=103:38:11739406783613::::FSP_ORG_ID,FSP_APEX_PAGE,FSP_PROJECT_ID:1303,23,110793>

[b-EMF] EMF-PORTAL
<https://www.emf-portal.org/en>

[b-EmfExpl] EMF Explained 2.0
<http://www.emfexplained.info/>

[b-ICNIRP 1998] [2] ICNIRP – International Commission on Non-Ionizing Radiation Protection (1998), *Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). Health Physics – Volume 74 – Issue 4 – pp. 494-522.*
<https://journals.lww.com/health-physics/citation/1998/04000/guidelines_for_limiting_exposure_to_time_varying.13.aspx>

[b-ICNIRP 2020] ICNIRP – International Commission on Non-Ionizing Radiation Protection (2020), *Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz). Health Physics*, 118(5), 2020, pp. 483 524.
<https://www.icnirp.org/cms/upload/publications/ICNIRPrfgdl2020.pdf>

[b-SCF012] SCF012/GSMA (2017), *Simplifying small cell installation: Harmonized principles for RF compliance (infographics).*
<https://scf.io/en/documents/012_IEC_equipment_classes_infographic.php>

[b-Baracca] Baracca, P., Weber, A., Wild, T., and Grangeat, C. (2018), *A Statistical Approach for RF Exposure Compliance Boundary Assessment in Massive MIMO Systems.*
<https://arxiv.org/abs/1801.08351>

[b-Kim] Kim, B. C., Yun, J. -H., Park, S. -O. (2012), *Uncertainty estimation for evaluating human exposure levels to RF electromagnetic fields from cellular base stations.* IEEE Transactions on Electromagnetic Compatibility Volume: 54, Issue: 2, pp. 246-253.
<https://ieeexplore.ieee.org/document/6142059>

[2] When reference [b-ICNIRP] is used, it applies to both [b-ICNIRP_1998] and [b-ICNIRP_2020].

[b-Thors] Thors, B., Furuskär, A., Colombi, D., and Törnevik, C. (2017), *Time-Averaged Realistic Maximum Power Levels for the Assessment of Radio Frequency Exposure for 5G Radio Base Stations Using Massive MIMO*, IEEE Access, Volume: 5, pp. 19711-19719. <https://ieeexplore.ieee.org/document/8039290>

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	Tariff and accounting principles and international telecommunication/ICT economic and policy issues
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	Transmission systems and media, digital systems and networks
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	**Protection against interference**
Series L	Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Telephone transmission quality, telephone installations, local line networks
Series Q	Switching and signalling, and associated measurements and tests
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities
Series Z	Languages and general software aspects for telecommunication systems

Printed in Switzerland
Geneva, 2022