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Supplements to ITU-T K-series Recommendations

Case studies of radio frequency-electromagnetic field (RF-EMF) assessment

Supplement 32 to ITU-T K-series Recommendations

Case studies of radio frequency-electromagnetic field (RF-EMF) assessment

Summary

Supplement 32 to ITU-T K-series Recommendations presents results of case studies of radio frequency-electromagnetic field (RF-EMF) exposure levels, including fifth generation (5G) systems, taken in different conditions and areas. All results of EMF exposure assessment were delivered by ITU-T members and include calculations and measurements of the RF-EMF exposure levels in the vicinity of different radio communication systems. RF-EMF exposure levels vary depending on the environment in which they are taken and type of radio communication systems that are in operation.

The results included in Supplement 32 to ITU-T K-series Recommendations provide information about RF-EMF exposure levels in real situations. The EMF exposure assessments are included in appendices.

Supplement 32 to ITU-T K-series Recommendations aims mainly to resolve the problem of EMF compliance assessments of base station systems through typical case studies including computation evaluation and measurement evaluation, and also provides the case support on implementation of Supplement 16 to ITU-T K-series Recommendations and of IEC 62232.

History *

Edition	Recommendation	Approval	Study Group	Unique ID
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Keywords

5G, assessment, case studies, computation, measurement, mMIMO, RF-EMF.

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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.

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Introduction

In the face of the rapid development of fifth generation (5G) networks using the new massive multiple input multiple output (mMIMO) technology, the rapid increase in the number of base stations (BSs) and continuous increases in transmission power, the electromagnetic radiation safety and the exposure level of 5G BSs have attracted attention from society and the public.

– In terms of the construction scale of 5G BSs, there are more than 200 5G commercialized networks around the world, and it was expected that the total number of 5G (Sub 6G) BSs in the world would exceed 3.3 million by the end of 2022, of which the total number of 5G BSs in China will exceed 2 million, accounting for more than 60% of worldwide construction. At the time of publication, China's 5G network has formed a relatively perfect hierarchical and layered coverage, covering all prefecture-level cities, 98% of counties and 80% of towns and townships in China.

– From the actual rate of 5G commercial networks of global operators, the maximum downlink rate of a single 100 M bandwidth of 5G (sub 6G) BS can generally reach between 1 Gbit/s to 2 Gbit/s, the overall average downlink rate has reached 800 Mbit/s to 1 200 Mbit/s, far exceeding the network capacity of 100 Mbit/s to 150 Mbit/s in the 4G era, highlighting the advantages of 5G super-large bandwidth.

– From the point of view of transmission power and coverage capacity, the transmission power of a 5G BS is usually much higher than that of a 4G BS due to the greater working bandwidth. At the time of publication, commercial 5G macro stations have rated maximum transmission power of 160 W, 200 W, 240 W and 320 W, far exceeding the 40 W to 60 W transmission power of 4G BSs. In addition, the working frequency band of 5G is usually higher, affected by high-frequency attenuation, the coverage radius of a 5G BS is about 300 m to 1 500 m, which is much smaller than that of a 4G BS of 1 000 m to 3 500 m. Obviously, in order to ensure the same coverage quality, 5G BSs are usually 3 to 5 times more numerous than 4G BSs.

– From the aspect of 5G BS antenna technology, it is well known that a traditional 2G/3G/4G BS adopts a fixed sector antenna with a 120° wide beam and gain of about 17 dBi with weak directionality, while a 5G BS adopts new mMIMO technology with strong beam-forming ability. The 5G mMIMO antenna can generate a strong narrow beam with gains of up to 25 dBi and half-power beam width of 5° to 30°, the narrow-beam has strong directivity and can be more focused on 5G user terminals, thus ensuring the high-speed transmission performance of 5G users with large bandwidth.

To sum up, considering the huge difference between 5G and traditional 3G/4G network systems, this Supplement on case studies of radio frequency-electromagnetic field (RF-EMF) assessment has been developed for the mobile networks including 5G networks, as necessary and meaningful work to improve the thorough understanding of 5G EMF compliance assessment to ensure the safety of the electromagnetic radiation environment around mobile BSs, and to help in the deployment of 5G wireless networks.

Supplement 32 to ITU-T K-series Recommendations

Case studies of radio frequency-electromagnetic field (RF-EMF) assessment

1 Scope

This Supplement describes best practice, based on a series of fifth generation (5G) case studies in which electromagnetic field (EMF) exposure levels are evaluated in accordance with [b-ITU-T K-Suppl.16] as well as [ITU-T K.100] and [IEC 62232]. The case studies presented in this Supplement involve intentionally irradiating 5G base stations (BSs) with operating frequencies less than 100 GHz, including the typical case studies of computation and measurement evaluation of the impact of a 5G BS on the surrounding electromagnetic environment quality in different application scenarios.

The case studies are provided for guidance and reference only, and are not a substitute for a thorough understanding of the requirements of the EMF compliance assessments for 5G wireless networks.

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.83]	Recommendation ITU-T K.83 (2022), *Monitoring of electromagnetic field levels*.
[ITU-T K.91]	Recommendation ITU-T K.91 (2022), *Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields*.
[ITU-T K.100]	Recommendation ITU-T K.100 (2021), *Measurement of radio frequency electromagnetic fields to determine compliance with human exposure limits when a base station is put into service*.
[ITU-R P.1238]	Recommendation ITU-R P.1238 (2023), *Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 450 GHz*.
[IEC 62232]	International Standard IEC 62232:2022, *Determination of RF field strength, power density and SAR in the vicinity of radio communication base stations for the purpose of evaluating human exposure*.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 antenna [ITU-T K.70].

3.1.2 assessment [IEC 62232]: Undertaking of an evaluation of "RF exposure from an EUT" in order to arrive at a judgement about comparison with the applicable exposure limits.

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

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

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

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

3.1.7 evaluation, ‹of an exposure metric› [IEC 62232]: Process of determining a value "of an exposure metric".

3.1.8 exposure [ITU-T K.52].

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

3.1.10 exposure limits [ITU-T K.70].

3.1.11 general public [ITU-T K.52].

3.1.12 *in-situ* RF exposure evaluation [IEC 62232]: Determination of *in-situ* RF exposure levels in the vicinity of a BS installation during operation.

3.1.13 main lobe [ITU-T K.100].

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

3.1.15 power density (*S*) [ITU-T K.83].

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

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

3.1.18 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.

3.1.19 transmitter [ITU-T K.70].

3.1.20 user equipment (UE) [b-IEC TR 62669]: Device used directly by an end-user to communicate in a mobile network.

3.2 Terms defined in this Supplement

None.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

AAU	Active Antenna Unit
2G	second Generation
3G	third Generation
4G	fourth Generation
5G	fifth Generation
BS	Base Station
CDF	Cumulative Distribution Function
EIRP	Equivalent Isotropically Radiated Power
eMBB	enhanced Mobile Broadband

EMF	Electromagnetic Field
LOS	Line of Sight
MIMO	Multiple Input Multiple Output
mMIMO	massive Multiple Input Multiple Output
NR	New Radio
OTA	Over-The-Air
PCI	Physical Cell ID
RF	Radio Frequency
Rx	Receiver
SSB	Synchronization Signal Block
TDD	Time Division Duplex
Tx	Transmitter
UE	User Equipment

5 Conventions

None.

6 Overview of case studies

Case studies presented in this Supplement have been chosen to illustrate typical radio frequency (RF) exposure assessments of 5G base stations (BSs) deployed in mobile networks; these include small cells and macro BSs using massive multiple input multiple output (mMIMO), such as 16, 32, 64, 128 transmitters/receivers (Tx/Rx) or only multiple input multiple output (MIMO) such as 2, 4, 8Tx/Rx.

The case studies address both measurements and computation techniques used for the three main applications of RF exposure evaluation specified in clause 5.2 of [IEC 62232].

7 Case study of RF-EMF compliance assessment of a 5G mMIMO macro BS site

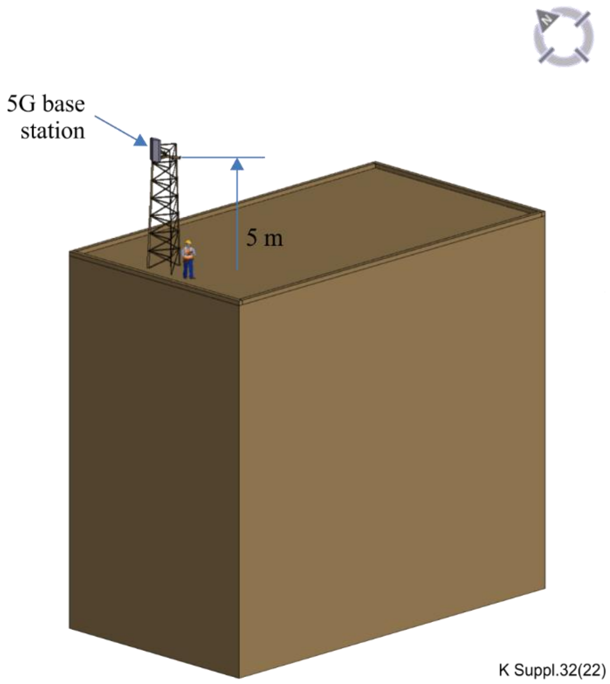
This case study illustrates a typical 5G new radio (NR) macro BS, which has an mMIMO array antenna with 64 antenna element sub-arrays and the same number of Tx and Rx, operating in medium frequency bands around 3.5 GHz. With this antenna, narrow traffic beams can be steered ±60° in the horizontal direction and ±20° in the vertical direction. Manufacturers of such BS products generally provide antenna radiation pattern data files, which are constructed by combining the patterns for all 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 BS was modelled. The BS has a rated maximum transmitted power of 200 W and uses time division duplex (TDD) with a maximum downlink duty cycle of 0.75 (i.e., the BS transmits only 75% of the time). As a conservative assumption for 5G NR, all power was assumed to be used for the traffic beams, i.e., no power was used for the control channel transmission. Figure 7-1 shows the site with the installed BS, and Table 7-1 provides data for the assessed product.

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

7.1 RF exposure compliance evaluation process

The evaluation was based on computations using the synthetic model and ray tracing algorithm 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.



NOTE – The lower part of the antenna is 5 m above the rooftop.

Figure 7-1 – The assessed 5G macro site with a 3.5 GHz mMIMO base station

Table 7-1 – Data for the assessed base station

Product name	5G NR base station (TDD)
Operating frequency band	3 400 MHz to 3 600 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
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 (53 dBm)
Maximum EIRP	76.7 dBm

7.2 RF exposure compliance evaluation

The actual maximum transmitted power of the array antenna was determined using the methodology described and the results from the statistical modelling studies referenced in [b-IEC TR 62669]. There are three main factors impacting the actual maximum power that contributes to the time-averaged RF-EMF exposure from mMIMO antennas:

1) TDDing (technology duty cycle);

2) scheduling time and spatial distribution of served users; and

3) BS utilization (traffic load).

Factor 2) 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 7-2 (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.

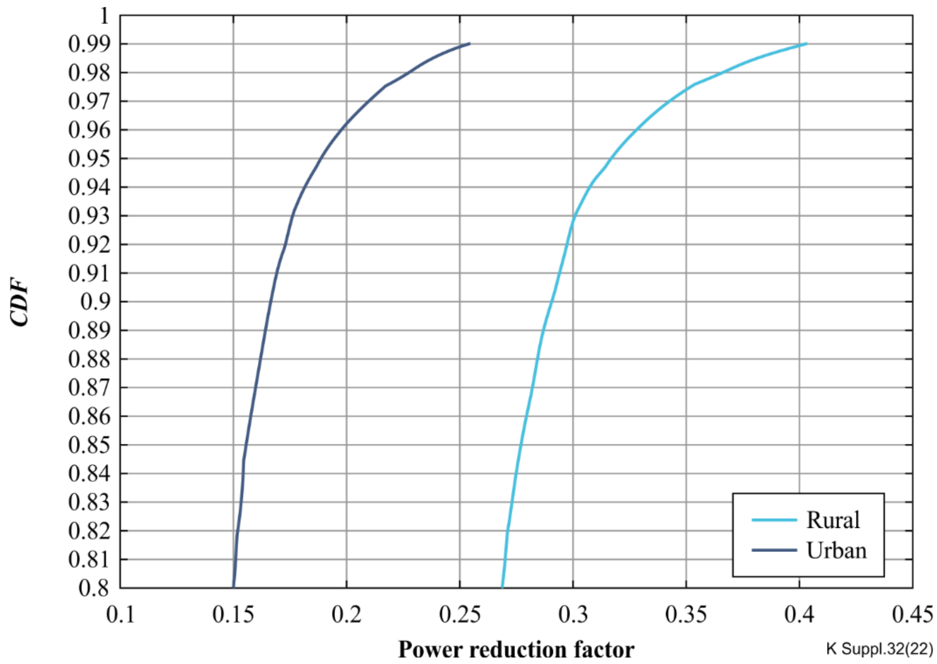
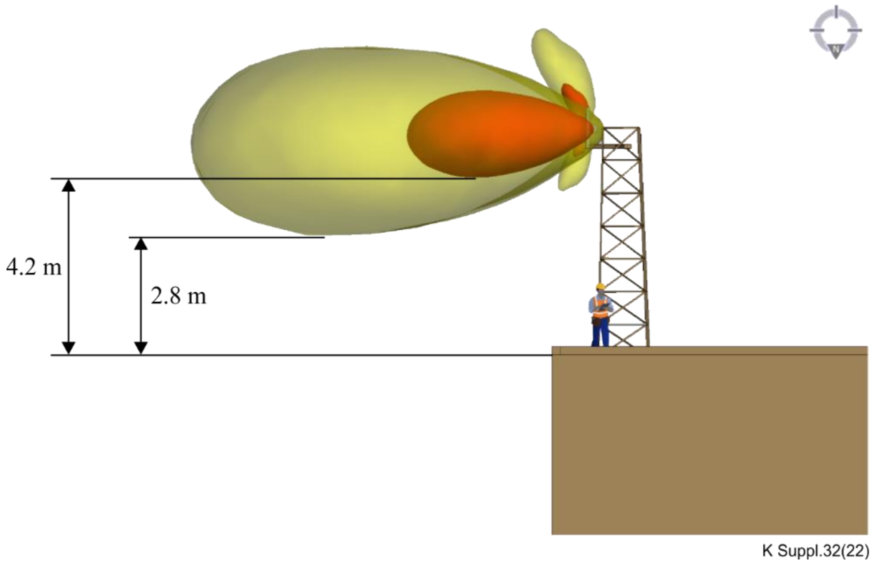


Figure 7-2 – Cumulative distribution functions of the power reduction factor for rural and urban installation scenarios of an 8 × 8 mMIMO antenna array [b-IEC TR 62669]

With a technology duty cycle of 0.75, and a power reduction factor of 0.32, the actual maximum power (averaged over 6 min) is 25% (0.75 × 0.32) of the rated maximum power. Consequently, an actual maximum power of 50 W (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 7-2). 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.

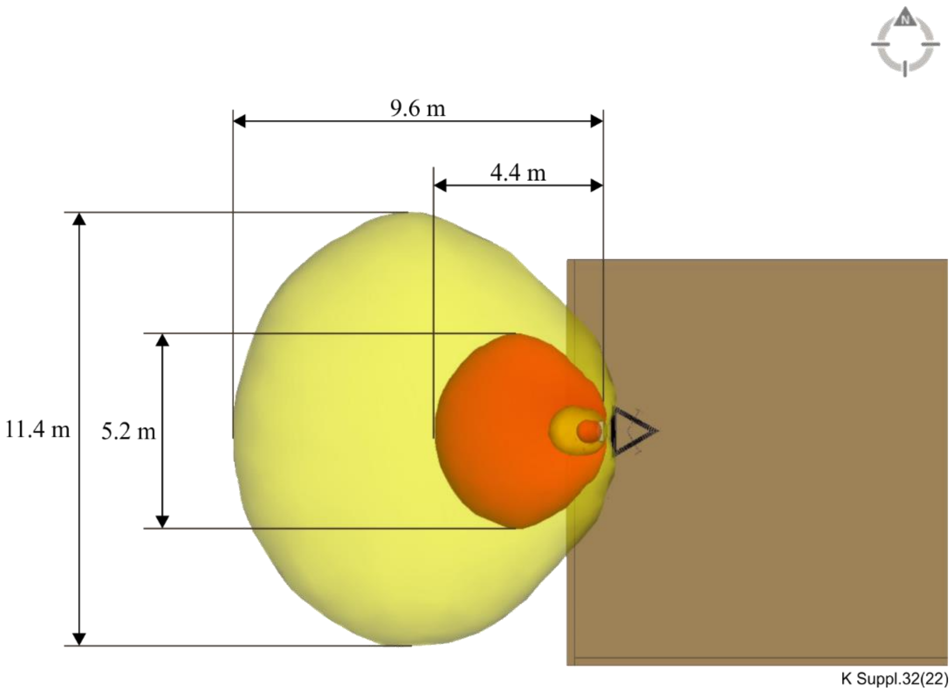
Figures 7-3 and 7-4 show the resulting compliance boundaries (exclusion zones) for the general public and workers at the evaluated 5G NR mMIMO rooftop site and for the actual maximum power of 50 W. The minimum vertical distance from the rooftop to the lower edge of the compliance boundary is 2.8 m for the general public and 4.2 m 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 BS antenna, the general public RF-EMF compliance distance is

9.6 m. 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.



NOTE – Vertical distances from the rooftop to the lowest point of the compliance boundaries are indicated.

Figure 7-3 – Vertical view of the computed compliance boundaries for the general public (yellow) and workers (red) around a 5G 3.5 GHz base station installed on a building rooftop [b-EmfExpl]



NOTE – The lengths and widths of the compliance boundaries are indicated.

Figure 7-4 – Horizontal view of the computed compliance boundaries for the general public (yellow) and workers (red) around a 5G 3.5 GHz base station installed on a building rooftop

8 Case study of 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 TDD with a mMIMO antenna transmitting at 27 GHz installed at an indoor 5G test and innovation laboratory in Southport, Australia. Figure 8-1 shows the environment in which the 5G small cell was installed.

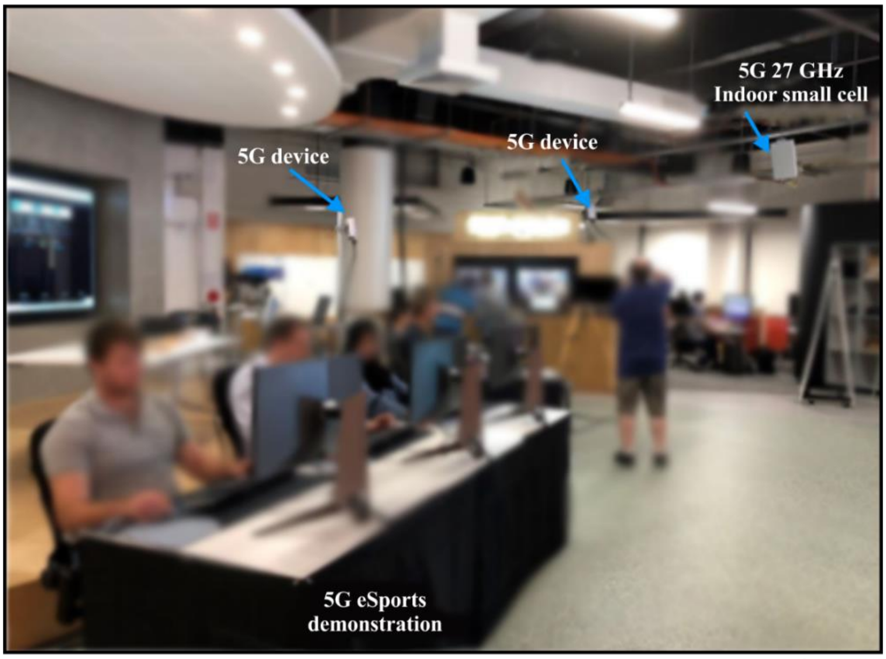


Figure 8-1 –The assessed indoor 5G small cell at the Southport 5G innovation laboratory [b-EmfExpl]

8.1 Small cell configuration

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

1) full power test mode (48 dBm EIRP);

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 not to 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.

8.2 Compliance evaluation process

This product installation compliance assessment follows the procedures specified 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 of [ITU-T K.100] specify the product installation classes where a simplified evaluation process is applicable based on the general public limits in [b-ICNIRP].

8.3 RF exposure compliance evaluation

The indoor small cell installation in the demonstration mode, shown in Figure 8-1, 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 that the product is installed according to instructions from the manufacturer and/or entity putting it 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 conditions described below:

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

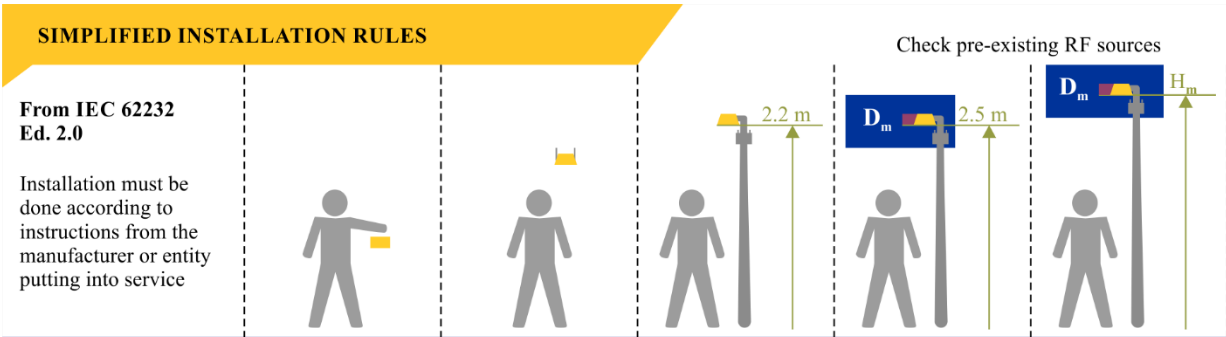
– the lowest radiating part of the antenna(s) is at a minimum height of 2.5 m above the general public walkway;

– 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 m ($5D_m$) in the main lobe direction (as determined by considering the half-power beam width) and within 0.7 m (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 8-2 (Figure is adapted from [b-SCF012] and [b-ITU-T K-Suppl.9]).



Installation class	E0	E2	E10	E100	E+
Total EIRP	N/A	≤ 2 W	≤ 10 W	≤ 100 W	No limit
Minimum height above walkway	None	None	2.2 m	2.5 m	H_m (calculation)
Exclusion zone	None, touch compliant	Provided in manufacturer's instructions small D_m not shown on the picture		Provided in manufacturer's instructions D_m in main lobe direction	
Check pre-existing RF sources	N/A	N/A	N/A	5 D_m in main lobe direction D_m in other directions	

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(Source: Small Cells Forum and GSMA)

Figure 8-2 – Simplified installation rules

9 5G mMIMO macro BSs of the three operators

9.1 General description

The case studies introduced in this clause are the *in-situ* RF exposure measurement evaluation of the 5G mMIMO macro BSs of China's three major operators (China Telecom, China Unicom, and China Mobile) working in the medium band (1 GHz to 6 GHz).

The RF-EMF compliance supervision of the operating 5G BS (installation class E+) with EIRP above 100 W in China is assessed by measuring whether the *in-situ* RF exposure level near a BS installation meets national limit standards.

Through case studies of RF-EMF measurement of a 5G mMIMO macro BS in different application scenarios, it is hoped to better understand the actual situations of 5G RF exposure so as to eliminate some misunderstandings about 5G EMF and facilitate the development of 5G networks, which is also the main purpose of the *in-situ* RF exposure measurement case studies in this clause.

Application scenarios of 5G mobile communication include enhanced mobile broadband (eMBB), ultra-reliable and low latency communication, and massive machine type communication, such as: data transmission, video interaction, game entertainment, virtual shopping, smart medical, industrial application and Internet of vehicles.

The maximum downlink rate of an operating 5G mMIMO macro BS can provide 1 000 Mbit/s to 1 500 Mbit/s under very good working conditions. Table 9-1 lists typical model parameters of the measured 5G macro BS for China's three operators.

Table 9-1 – Typical parameters of the measured 5G mMIMO macro base stations

No.	Operator	Rated transmitted power (W)	Working frequency band (MHz)	Carrier bandwidth (MHz)	Antenna gain (dBi)	Tx/Rx (TR)	BS antenna height from ground (m)	Antenna tilt angle (°)
1	China Telecom and China Unicom (Shared 5G BS)	320	3 400-3 600	200	25	64	8–50	5-20
2	China Telecom	320	3 400-3 500	100	25	64	8–50	5-20
3	China Telecom	200	3 400-3 500	100	23–25	64 32	8–50	5-20
4	China Unicom	320	3 500-3 600	100	25	64	8–50	5-20
5	China Mobile	200	2 515-2 675	160	23–25	64 32	8–50	5-20

9.2 Measurement implementation

9.2.1 Evaluation process

Using the quick start guide in clause 5.1 of [IEC 62232], the following steps for the measurement campaign were identified:

1) evaluation type: clause 6.3 of [IEC 62232] – *in-situ* RF exposure evaluation or assessment process;

2) measurement method: clause 8.2.2 of [IEC 62232] – RF field strength and power density measurements, and clause I.1;

3) RF field strength and power density measurements: clause B.4.2 of [IEC 62232] – *in-situ* RF exposure measurements;

4) other general requirements for 5G BS *in-situ* RF-EMF exposure measurements: clause 9.6 of [b-ITU-T K-Suppl.16];

5) uncertainty of 5G compliance assessments: clause 9 of [IEC 62232], [ITU-T K.91] and [ITU-T K.100].

6) records and reporting: clause 10 of [IEC 62232] and clause I.4 – record format of RF-EMF *in-situ* measurement for 5G BS systems.

9.2.2 Methodology

In order to accurately distinguish and measure *in-situ* RF exposure to an operating 5G macro BS and avoid the interference of other network systems on the measurement results, the instrument in these case studies adopts the frequency selective measurement system. This instrument with different measuring ranges and frequency ranges may be selected according to specific requirements, such measuring instruments shall comply with Table I.1.

All the 5G macro BSs selected in the measurement case studies are typical BSs installed in urban areas, residential areas or around roads, such as single pole tower BSs (see Figure 9-1) or house roof BSx (see Figure 9-2).

Figure 9-1 – Single pole tower base stations

Figure 9-2 – House roof base stations

The basic parameters of the 5G BS sites are as follows:

– height of the BS antenna is 8 m to 50 m from the ground;

– measurement area is within a radius of 10 m to 140 m covered by the BS antenna;

– measurement height is 1.5 m to 2.0 m above the ground;

– rated transmission power of 5G macro BS is 200 W and 320 W with mMIMO of 32 or 64Tx/Rx;

– measurement power density is averaged over any continuous 6 min;

– measurements are conducted between 09:00 and 17:00 on clear business days.

Meantime, in order to fully understand the RF exposure level of the operating mMIMO 5G macro BS, to obtain the relationship between 5G EMF changes with downlink traffic rate, case studies were conducted in the following three application scenarios with different downlink speed ranges:

1) (extremely) high-speed downlink traffic rate: above 400 Mbit/s, the typical eMBB.

2) medium-speed downlink traffic rate: between 100 Mbit/s and 400 Mbit/s.

3) low-speed downlink traffic rate: below 100 Mbit/s, common and daily application scenarios.

9.2.3 Measurement layout

Note especially that measurements of *in-situ* RF exposure measurement for 5G and 3G/4G differ. For a 5G BS, at least one 5G UE should be connected to the BS under test and measured when there is downlink traffic.

Figure 9-3 shows a simple layout of the *in-situ* RF-EMF exposure measurement for a 5G BS site.

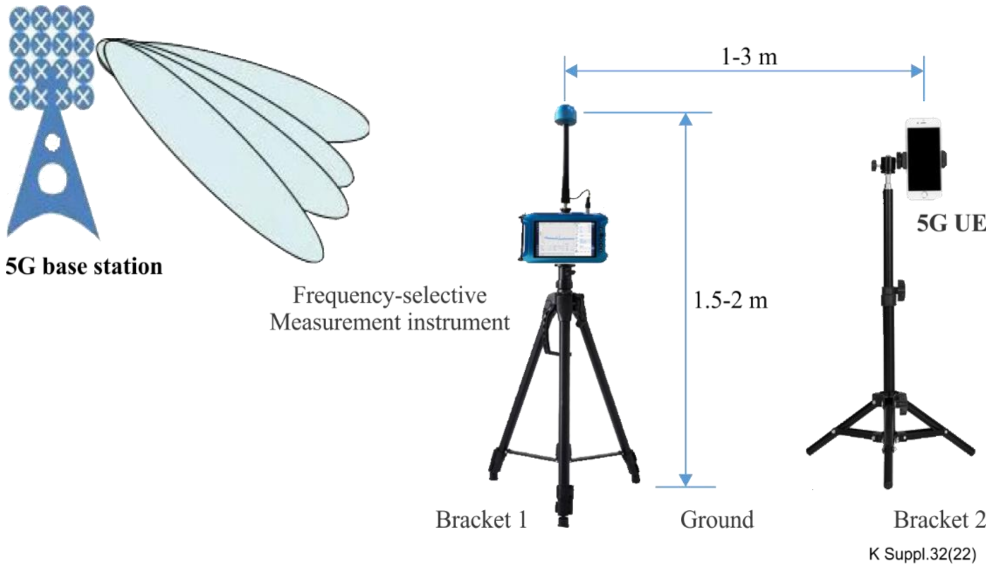

Figure 9-3 – *In-situ* RF-EMF exposure measurement layout of a 5G BS

9.2.4 Reporting

Clause I.4 provides a typical test report according to the template in clause 10 of [IEC 62232] and detailing the *in-situ* RF exposure measurement methodology and measurement result record form.

9.3 Measurement results

Clause 9.3.1 reports the *in-situ* RF exposure measurements of 5G mMIMO macro BSs of the three operators of China in downlink traffic application scenarios where speed is high, medium and low.

9.3.1 Case studies for high-speed application scenarios

9.3.1.1 High-speed case for China Telecom's 5G mMIMO BS

Table 9-2 and Table 9-3 list two *in-situ* EMF measurement case results in extremely high-speed application scenarios and in the direction of the main lobe of the operating 320 W 5G BS of China Telecom.

Furthermore, this is the RF exposure assessment based on actual maximum speed downlink traffic of the operating 5G mMIMO macro BS.

Table 9-2 – High-speed case 1 for China Telecom's 5G mMIMO BS

Points	BS height (m)	Distance from the BS antenna		Measuring value – Integral mean value of 6 min		Measuring frequency band (MHz)	Bandwidth (MHz)	Continuous down rate (Mbit/s) for 6 min (extremely high-speed)
		Vertical (m)	Horizontal (m)	Electric field intensity E (V/m)	Power density S (W/m^2)			
1	14	12.3	26	7.9	0.17	3 400 ~ 3 500	100	800-1 200
2	14	12.3	40	6.5	0.11	3 400 ~ 3 500	100	800-1 200
3	14	12.3	55	5.9	0.09	3 400 ~ 3 500	100	800-1 200
NOTE – China's exposure limit 13.3 V/m.								

Table 9-3 – High-speed case 2 for China Telecom's 5G mMIMO BS

Points	BS height (m)	Distance from the BS antenna		Measuring value – Integral mean value of 6 min		Measuring frequency band (MHz)	Bandwidth (MHz)	Continuous down rate (Mbit/s) for 6 min (extremely high-speed)
		Vertical (m)	Horizontal (m)	Electric field intensity E (V/m)	Power density S (W/m^2)			
1	47	7	25	9.9	0.26	3 400 ~ 3 500	100	800-1 200
2	47	7	37	8.4	0.19	3 400 ~ 3 500	100	800-1 200
3	47	45	29	4.5	0.05	3 400 ~ 3 500	100	800-1 200
NOTE – China's exposure limit 13.3 V/m.								

9.3.1.2 High-speed case for China Unicom's 5G mMIMO BS

Table 9-4 and Table 9-5 list two *in-situ* EMF measurement case results in extremely high-speed application scenarios and in the direction of the main lobe of the operating 320 W 5G BS of China Unicom.

Table 9-4 – High-speed case 1 for China Unicom's 5G mMIMO BS

Points	BS height (m)	Distance from the BS antenna		Measuring value – Integral mean value of 6 min		Measuring frequency band (MHz)	Bandwidth (MHz)	Continuous down rate (Mbit/s) for 6 min (extremely high-speed)
		Vertical (m)	Horizontal (m)	Electric field intensity E (V/m)	Power density S (W/m^2)			
1	30	28.3	67	7.2	0.14	3 500-3 600	100	800-1 200
2	30	28.3	81	6.7	0.12	3 500-3 600	100	800-1 200
3	30	28.3	101	5.6	0.08	3 500-3 600	100	800-1 200
NOTE – China's exposure limit 13.5 V/m.								

Table 9-5 – High-speed case 2 for China Unicom's 5G mMIMO BS

Points	BS height (m)	Distance from the BS antenna		Measuring value – Integral mean value of 6 min		Measuring frequency band (MHz)	Bandwidth (MHz)	Continuous down rate (Mbit/s) for 6 min (high-speed)
		Vertical (m)	Horizontal (m)	Electric field intensity E (V/m)	Power density S (W/m^2)			
1	18	4.7	16	5.5	0.081	3 500-3 600	100	400-800
2	18	4.7	20	5.0	0.065	3 500-3 600	100	400-800
3	18	4.7	50	4.1	0.045	3 500-3 600	100	400-800
4	18	4.7	70	3.1	0.026	3 500-3 600	100	400-800
NOTE – China's exposure limit 13.5 V/m.								

9.3.1.3 High-speed case for the shared 5G mMIMO BS by China Telecom and China Unicom

Table 9-6 lists EMF measurement case results in high-speed application scenarios and in the direction of the main lobe of the shared 320 W 5G mMIMO BS by China Telecom and China Unicom.

Table 9-6 – High-speed case for the shared 5G mMIMO BS by China Telecom and China Unicom

Points	BS height (m)	Distance from the BS antenna		Measuring value Integral mean value of 6 min		Measuring frequency band (MHz)	Bandwidth (MHz)	Continuous down rate (Mbit/s) for 6 min (extremely high-speed)
		Vertical (m)	Horizontal (m)	Electric field intensity E (V/m)	Power density S (W/m^2)			
1	23.6	21.9	64	8.8	0.21	3 400-3 600	200	800-1 200
2	23.6	21.9	68	8.1	0.17	3 400-3 600	200	800-1 200
3	23.6	21.9	72	8.7	0.20	3 400-3 600	200	800-1 200
NOTE – China's exposure limit 13.5 V/m.								

Figure 9-4 shows the real-time spectrum distribution for the shared 5G mMIMO BS with 200 MHz bandwidth in high-speed downlink application when China Telecom's 100 MHz and China Unicom's 100 MHz work simultaneously.

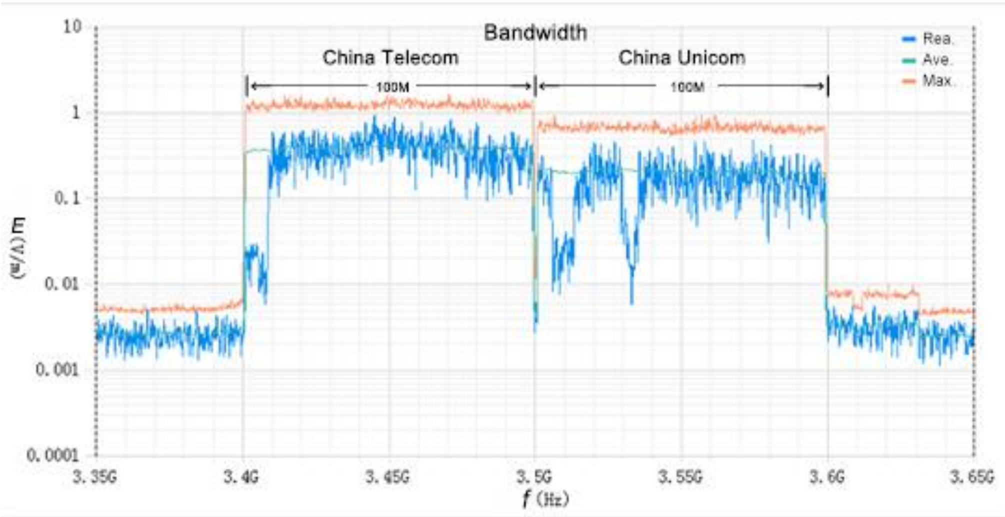

Figure 9-4 – Real-time spectrum distribution of the 200 MHz bandwidth of the shared 5G BS working simultaneously in the high-speed scenarios (China Telecom + China Unicom)

9.3.1.4 High-speed case for China Mobile's 5G BS

Table 9-7 lists results from an EMF measurement case in high-speed application scenarios and in the direction of the main lobe of the 200 W 5G mMIMO BS antenna by China Mobile.

Table 9-7 – High-speed case for China Mobile's 5G mMIMO BS

Points	BS height [m]	Distance from the BS antenna		Measuring value – Integral mean value of 6 min		Measuring frequency band (MHz)	Bandwidth (MHz)	Continuous down rate for (Mbit/s) 6 min (high-speed)
		Vertical [m]	Horizontal [m]	Electric field intensity E (V/m)	Power density S (W/m^2)			
1	25	24	10	4.2	0.046	2 515 ~ 2 675	160	400-800
2	25	24	20	4.5	0.054	2 515 ~ 2 675	160	400-800
3	25	24	30	4.5	0.053	2 515 ~ 2 675	160	400-800
4	25	24	50	4.3	0.049	2 515 ~ 2 675	160	400-800
5	25	24	100	4.4	0.050	2 515 ~ 2 675	160	400-800
NOTE – China's exposure limit 12.3 V/m.								

9.3.2 Case studies for medium-speed application scenarios

9.3.2.1 Medium-speed case for China Telecom's 5G mMIMO BS

Table 9-8 lists results from EMF measurement cases in medium-speed application scenarios and in the direction of the main lobe of the 320 W 5G mMIMO BS antenna of China Telecom.

Table 9-8 – Medium-speed case for China Telecom's 5G mMIMO BS

Points	BS height [m]	Distance from the BS antenna		Measuring value – Integral mean value of 6 min		Measuring frequency band (MHz)	Bandwidth (MHz)	Continuous down rate for (Mbit/s) 6 min (high-speed)
		Vertical [m]	Horizontal [m]	Electric field intensity E (V/m)	Power density S (W/m^2)			
1	32.5	31	28	3.0	0.024	3 400 ~ 3 500	100	100-400
2	32.5	31	34	3.6	0.034	3 400 ~ 3 500	100	100-400
3	32.5	31	36	4.1	0.045	3 400 ~ 3 500	100	100-400
4	32.5	31	50	2.8	0.021	3 400 ~ 3 500	100	100-400
NOTE – China's exposure limit 13.3 V/m.								

9.3.2.2 Medium-speed case for China Unicom's 5G mMIMO BS

Table 9-9 lists results from EMF measurement cases in medium-speed application scenarios and in the direction of the main lobe of the 320 W 5G mMIMO BS of China Unicom.

Table 9-9 – Medium-speed case for China Unicom's 5G mMIMO BS

Points	BS height [m]	Distance from the BS antenna		Measuring value: Integral mean value of 6 min		Measuring frequency band (MHz)	Bandwidth (MHz)	Continuous down rate for (Mbit/s) 6 min (medium-speed)
		Vertical [m]	Horizontal [m]	Electric field intensity E (V/m)	Power density S (W/m^2)			
1	20	18	22	4.0	0.044	3 500 ~ 3 600	100	100-400
2	20	18	32	3.9	0.041	3 500 ~ 3 600	100	100-400
3	20	18	48	4.8	0.061	3 500 ~ 3 600	100	100-400
4	20	18	116	3.0	0.023	3 500 ~ 3 600	100	100-400
NOTE – China's exposure limit 13.5 V/m.								

9.3.2.3 Medium-speed case for China Mobile's 5G mMIMO BS

Table 9-10 lists results from EMF measurement cases in medium-speed application scenarios and in the direction of the main lobe of the 200 W 5G mMIMO BS of China Mobile.

Table 9-10 – Medium-speed case for China Mobile's 5G mMIMO BS

Points	BS height [m]	Distance from the BS antenna		Measuring value: Integral mean value of 6 min		Measuring frequency band (MHz)	Bandwidth (MHz)	Continuous down rate for (Mbit/s) 6 min (medium-speed)
		Vertical [m]	Horizontal [m]	Electric field intensity E (V/m)	Power density S (W/m^2)			
1	19	18	30	3.9	0.040	2 515 ~ 2 675	160	100-400
2	19	18	50	3.8	0.038	2 515 ~ 2 675	160	100-400
3	19	18	110	4.6	0.056	2 515 ~ 2 675	160	100-400
4	19	18	140	3.6	0.034	2 515 ~ 2 675	160	100-400
NOTE – China's exposure limit 12.3 V/m.								

9.3.3 Case studies for low-speed application scenarios (common and daily application scenarios)

9.3.3.1 Low-speed case for China Telecom's 5G mMIMO BS

Table 9-11 lists results from an EMF measurement case in low-speed application scenarios (namely the common and daily application scenarios) and in the direction of the main lobe of the 320 W 5G mMIMO BS of China Telecom.

Table 9-11 – Low-speed case for China Telecom's 5G mMIMO BS

Points	BS height [m]	Distance from the BS antenna		Measuring value		Measuring frequency band (MHz)	Bandwidth (MHz)	Continuous down rate for (Mbit/s) 6 min (low-speed)
				Integral mean value of 6 min				
		Vertical [m]	Horizontal [m]	Electric field intensity E (V/m)	Power density S (W/m^2)			
1	8m	6.3	22	1.3	0.004 7	3 400 ~ 3 500	100	< 100
2	8m	6.3	28	1.7	0.007 4	3 400 ~ 3 500	100	< 100
3	8m	6.3	40	2.0	0.011 0	3 400 ~ 3 500	100	< 100
NOTE – China's exposure limit 13.3 V/m.								

9.3.3.2 Low-speed case for China Unicom's 5G mMIMO BS

Table 9-12 lists results from EMF measurement cases in low-speed application scenarios (daily application scenarios) and in the direction of the main lobe of the 320 W 5G mMIMO BS antenna of China Unicom.

Table 9-12 – Low-speed case for China Unicom's 5G mMIMO BS

Points	BS height [m]	Distance from the BS antenna		Measuring value		Measuring frequency band (MHz)	Bandwidth (MHz)	Continuous down rate for (Mbit/s) 6 min (low-speed)
				Integral mean value of 6 min				
		Vertical [m]	Horizontal [m]	Electric field intensity E (V/m)	Power density S (W/m^2)			
1	12.5	10.8	18	2.9	0.022 8	3 500 ~ 3 600	100	< 100
2	12.5	10.8	25	2.6	0.017 5	3 500 ~ 3 600	100	< 100
3	12.5	10.8	36	2.4	0.015 0	3 500 ~ 3 600	100	< 100
4	12.5	10.8	50	2.0	0.010 4	3 500 ~ 3 600	100	< 100
NOTE – China's exposure limit 13.5 V/m.								

9.3.3.3 Low-speed case for China Mobile's 5G mMIMO BS

Table 9-13 lists results from EMF measurement cases in low-speed application scenarios (daily application scenarios) and in the direction of the main lobe of the 200 W 5G mMIMO BS antenna of China Mobile.

Table 9-13 – Low-speed case for China Mobile's 5G mMIMO BS

Points	BS height [m]	Distance from the BS antenna		Measuring value		Measuring frequency band (MHz)	Bandwidth (MHz)	Continuous down rate for (Mbit/s) 6 min (low-speed)
				Integral mean value of 6 min				
		Vertical [m]	Horizontal [m]	Electric field intensity E (V/m)	Power density S (W/m^2)			
1	16.7	15	10	1.9	0.009 23	2 515 ~ 2 675	160	< 100
2	16.7	15	15	1.9	0.009 39	2 515 ~ 2 675	160	< 100
3	16.7	15	20	1.9	0.009 56	2 515 ~ 2 675	160	< 100
4	16.7	15	25	1.9	0.009 76	2 515 ~ 2 675	160	< 100
5	16.7	15	30	1.8	0.008 63	2 515 ~ 2 675	160	< 100
NOTE – China's exposure limit 12.3 V/m.								

9.3.4 Case analysis

This clause reports EMF measurement case studies conducted on typical 5G mMIMO macro BSs operated by three major operators in China, according to the measurement results in Tables 9-2 to 9-13 under the following conditions:

– three different speed range application scenarios: high, medium and low;

– coverage radius of BS is 10 m to 140 m and the BS height is 8 m to 47 m;

– 5G mMIMO macro BSs with rated transmission power of 320 W and 200 W.

The maximum average power density within 6 min in the main lobe beam of 5G BSs and in the vicinity of a BS installation during operation are as follows:

– extremely high speed (800 Mbit/s to 1 200 Mbit/s): ≤ 25.8 μW/cm^2 (0.258 W/m^2);

– high speed (400 Mbit/s to 800 Mbit/s): ≤ 8.1 μW/cm^2 (0.081 W/m^2);

– medium speed (400 Mbit/s to 800 Mbit/s): ≤ 6.13 μW/cm^2 (0.061 3 W/m^2);

– low speed (< 100 Mbit/s): ≤ 2.28 μW/cm^2 (0.022 8 W/m^2).

Obviously, the above three operators of 5G EMF measurement results are significantly lower than the limits of [b-GB 8702], which specifies the exposure limit to be within 40 μW/cm^2 and 67 (0.4-0.67 W/m^2) listed in Table I.2, and also much lower than the guideline 1 000 μW/cm^2 (10 W/m^2) limit in [b-ICNIRP] and [b-IEEE C95.1].

9.4 Conclusion

Considering that a 5G mMIMO macro BS has a beam-forming feature and strong beam directivity, which can provide very high download rate, in order to more truly reflect its RF-EMF exposure, the case studies in this clause are especially aimed at 5G EMF measurement under continuous high-speed application scenarios.

In fact, the high-speed downlink is the most severe application for measuring RF-EMF exposure. The foregoing measurement results are below Chinese and ICNIRP exposure limits, even in the most severe application scenarios of 5G mMIMO macro BSs.

10 National survey in Uganda

This clause provides a summary of the results and findings from the national survey of EMF exposures conducted in Uganda and the implementation of the recommendations from the survey as a post regulatory intervention of the Uganda Communications Commission (UCC).

The aim of the survey was to conduct EMF exposure measurements, assessments, and interviews to determine the magnitude of uncertainty among the public.

Specifically, the survey was intended to:

a. Assess the compliance of the telecommunications installations with the internationally specified standards and requirements.

b. Assess the likelihood of human exposure to the radiation/emissions from the antennas at these installations.

c. Evaluate the magnitude of public uncertainty among persons living in proximity to the base station sites.

The survey which was specific to public exposure, adopted a mixed methods approach that involved EMF measuring equipment, calculations, as well as conducting face to face interviews using a well designed and tested questionnaire. The survey sample was generated from a combined list of all the base stations from the mobile networks. The survey involved a two-tier level of assessment: conducting EMF exposure assessment and conducting interviews to determine the magnitude of uncertainty among the public.

10.1 Measurements of the RF EMF exposure levels

The technical assessment of the survey was guided by the international standards and guidelines to which Uganda subscribes as indicated in clause 2. The measurements were taken using tools: Aaronia AG analyser (Spectran HF 60105, 1 MHz - 9.4 GHz), Aaronia Omnilog antenna 90200, 700 MHz - 2.5 GHz, Aaronia Hyperlog directional antenna 60100 EMC, 680 MHz - 10 GHz and a tripod stand. The technical assessments considered the exposure levels from the antennas at the base station sites in comparison with the ICNIRP public reference levels. Deriving ICNIRP maximum value = (power density received from measurement/incident power density)%; (S/Sinc)% as per the frequency range, i.e.

– Frequency range 400-2000 MHz; [S/[*f*/200]]%

– Frequency range 2-300 GHz; (S/10)%

Results from assessment are compared with the ICNIRP public reference level. A value of 100% or more indicates emissions have exceeded the reference levels.

At each selected location, the highest signal strength along with the respective frequency and power density were read off for the selected frequency band. The downlink frequency bands (assignment status of access frequency bands in Uganda as of March 2021) for: 800 MHz, 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz were selected at each location and power density recorded for each band. The assessment applied the ICNIRP 2020 guidelines. A 60-second averaging time for measurements was sufficient, except in cases where there was a significant variation in exposure from the results at a specific site that required measurement across the 30-minute interval.

The assessments (measurement and calculation) parameters considered for this survey are indicated in Table 10-1.

Table 10-1 – Survey measurement and calculation parameters

Location	Signal strength (dBm)	Frequency *F* (MHz)	Power density S (W/m²)	ICNIRP max Value	Summation of ICNIRP max at each selected location for all frequency bands considered
District, site name/GPS location as per sample selection given (indicate whether single, shared or collocated). Shared site may give different readings of GPS location and site name. Same as collocated site.	Highest signal strength read off at each selected location at a site for frequency bands considered.	Frequencies recorded.	Power density recorded for each frequency recorded.	Calculation for each measurement received.	Summation of ICNIRP max value at each selected location at a given site

Measurements were conducted at 360 sites, including: single[2], shared[3] or collocated[4] sites. Figure 10-1 shows a visual representation of selected sites on Google Earth Pro.

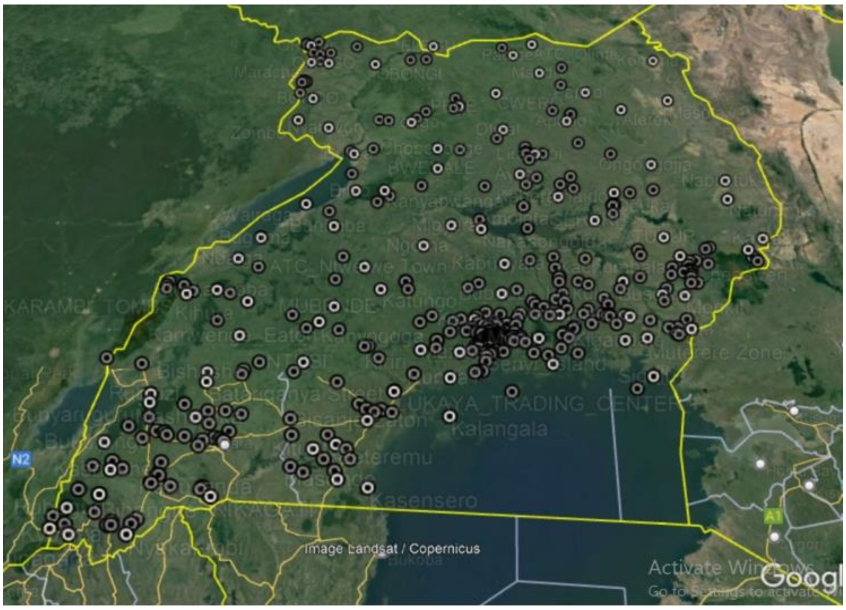

Figure 10-1 – Visual representation of selected sites on Google Earth Pro

Figure 10-2 shows the mean ICNIRP maximum values (%) across the regions where measurements were taken. The results showed that at all sites where measurements were conducted, the public reference levels defined under the ICNIRP guidelines were a very small percentage.

2 In this survey: a site with only one base station.

3 In this survey: a site with two or more base station sharing passive infrastructure like mast or rooftop.

4 In this survey: a site at which two or more base stations are on same ground [including roof tops] within in a distance 0-70 m.

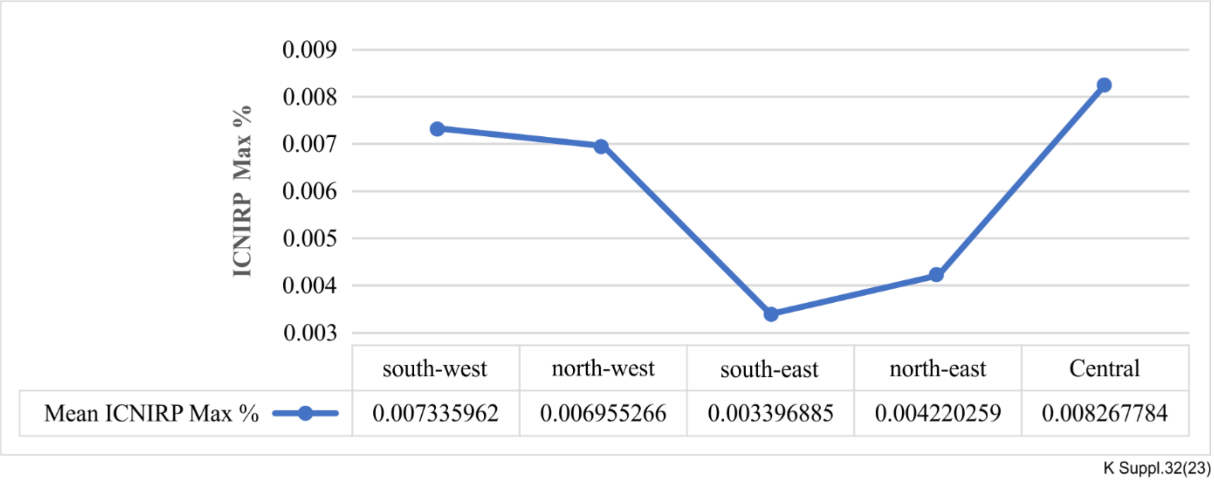

Figure 10-2 – Mean ICNIRP max values across regions

It can be seen in Figure 10-2 that the highest mean value for the ICNIRP maximum value (%) was 0.008%, which is a very small fraction from the public reference level of the ICNIRP guidelines (i.e., 100%).

Notably, the results suggest that there was generally a negligible variation in terms of exposure throughout various environments selected for the assessment. Whereas the results of the collocated sites display a slightly higher decimal than for the single and shared sites as shown in Figure 10-3, there is still no appreciable difference between the results from the single, shared, and collocated sites.

The collocated sites displayed slightly higher values than the single and shared sites, but still very much lower than the public reference level of the ICNIRP guidelines.

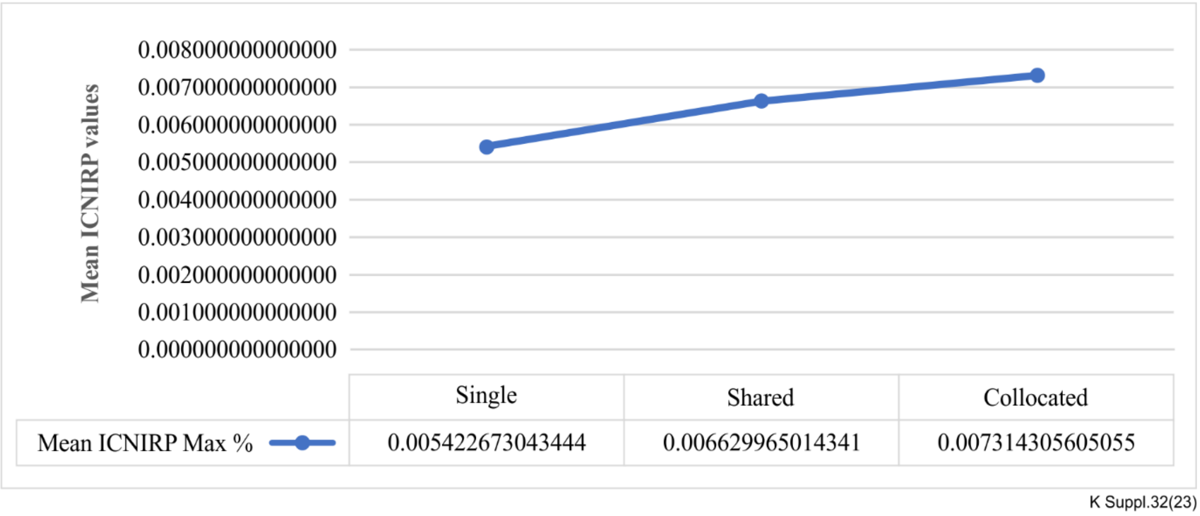

Figure 10-3 – Mean ICNIRP Max% for single, shared, and collocated sites

These results can thus suggest that the emissions from the sites are within the acceptable limits of the public reference level under the ICNIRP guidelines.

The findings from this survey indicate that:

The highest measurement levels are way below the public reference level of the ICNIRP guidelines, which would suggest that the base stations where assessments were conducted are safe for the public and not likely to pose any harm, and from analysis, the results are indicative that the base station sites are compliant.

10.2 Face to face interviews

Face to face interviews were conducted with members of the public found settled in neighbouring areas to the selected base station sites, using an open-ended questionnaire. The interviews were conducted to evaluate the magnitude of the public uncertainty and concern regarding living in proximity to the base station sites. Selection of the respondents was random, alternating between gender (Male and Female). At most three persons were interviewed around each selected site. Data was collected using the personal data assistant (PDA).

The findings from the public interviews on the level of uncertainty for persons living near the base station sites was assessed through public interviews. The full report revealed the following:

– About seven (7) in every ten (10) respondents (71.3%) were aware of the network service and infrastructure provider in their community. This is because some members were sensitized and involved prior to the deployment of the base stations, while others were motivated by network improvements, and recognizing the branded vehicles during site construction.

– Approximately eight (8) in every ten (10) respondents (80.3%) knew why base station sites are deployed near human settlements.

– Approximately six (6) in every ten (10) respondents (63.3%) were unaware of any community sensitization and consultation prior to site development.

– Similarly, nearly six (6) in every ten (10) respondents had no substantial concerns or worry about the deployment of base station sites near human settlements.

– Four (4) out of ten (10) respondents (40%) expressed concern and worry about the deployment of base station sites near human settlements. These concerns included, among others: noise from the generator, poor network connections, health risks such as cancer related illness, male infertility and headaches, devaluation of land, lack of privacy, and limited community consultations and awareness regarding the risks. Additionally, the analysis demonstrated that a person's level of education had little or no bearing on their uncertainty regarding the presence of base station sites in their proximity.

The results from the public interviews conducted to evaluate public concerns around base station sites inform on the need for adequate awareness and sensitization to create confidence among the communities.

10.3 Implementation of recommendations from the national survey

The following recommendations were proposed and implemented as a post survey regulatory action:

a. **Report dissemination**: The report was uploaded on the UCC website on the link: https://www.ucc.co.ug/wp-content/uploads/2022/09/National-EMF-survey-August-2022.pdf for all target groups. The report was also submitted during the meeting of the ITU-T SG in October 2022 for guiding other countries that are in the process of conducting similar assessments to align with objectives and methodology used.

b. **Sharing the findings of the report with key influences**: The findings of the report were shared through a sensitisation and awareness dialogue to: communicate the results of the survey, to empower decision-makers and selected stakeholders with reliable information to promote transparency and to address the resistance of timely deployment of telecommunications infrastructure amidst communities. Planned ahead are continuous sensitization of the public through talk shows and social media platforms.

c. **Updating the FAQs on EMF and safety**: The FAQs of RF exposure around telecommunications base stations were revised and updated to incorporate findings from the public interviews.

The public interviews indicated that a person's level of education has no bearing on uncertainty about the presence of base station sites in their proximity and underscored the need for more awareness to increase confidence among the communities. To fulfil its regulatory obligations and interventions, UCC developed a course of action as feedback from the findings from this report.

11 The 5G mmWave RF-EMF exposure level test based OTA

Table 11-1 shows the electromagnetic-field (EMF) radiation exposure limit requirements of China's national standards and international standards for 5G millimetre wave FR2 band.

Table 11-1 – mmMave FR2 band EMF radiation exposure level limit requirements

5G FR2 (GHz)	China's standard	International standard	
	GB 8702	ICNIRP 2020	IEEE C95.1
	Power density limit (W/m²)		
24.25 ~ 52.6	≤ 2.00	≤ 10	≤ 10

As can be seen from Table 11-1, the Chinese national standard requires the electromagnetic radiation exposure level (power density) of 5G mmWave FR2 band to be ≤ 2 W/m^2, while the two international standards of ICNIRP and IEC require the FR2 band exposure to be ≤ 10 W/m^2. Obviously, the limit requirement of China's national standard is about 5 times stricter than that of the international standard.

11.1 Methodology

The purpose of the test is to verify the extremely narrow beam emitted by 5G mmWwav AAU with large mMIMO antenna. Under the extreme application scenarios of continuous high-speed downlink rate up to 4 Gbit/s, through an over-the-air (OTA) chamber environment to simulate the beam propagation in free space, the EMF radiation value of millimetre wave beam at different points in horizontal and vertical directions is measured respectively, then the width of the mmWave beam is obtained.

Among the measurements is the OTA free space measurement of the actual maximum EMF value, according to Table 1 of [b-GB 8702] (China's national electromagnetic radiation limits standard requirements). This is to verify that the actual measurement results are basically in line with the results of theoretical calculation. If the two results are basically close, it can be assumed that this case study of EMF measurement is successful and that the results are credible. Furthermore, the maximum EMF compliance boundary of the 5G mmWave in the 26 GHz band can be determined.

11.2 5G mmWave EMF test environment

The test environment is built in the far-field OTA anechoic chamber. The overall size of the OTA chamber is 9.5 m (length) × 4.7 m (width) × 2.5 m (height), and the effective distance between the 5G mmWave AAU base station and the probe of the EMF radiation tester is 7 m. The EMF radiation tester used to measure the FR2 band must meet the standard of [IEC 62232]. The test layout is shown in Figure 11-1, and the OTA chamber shown in Figure 11-2.

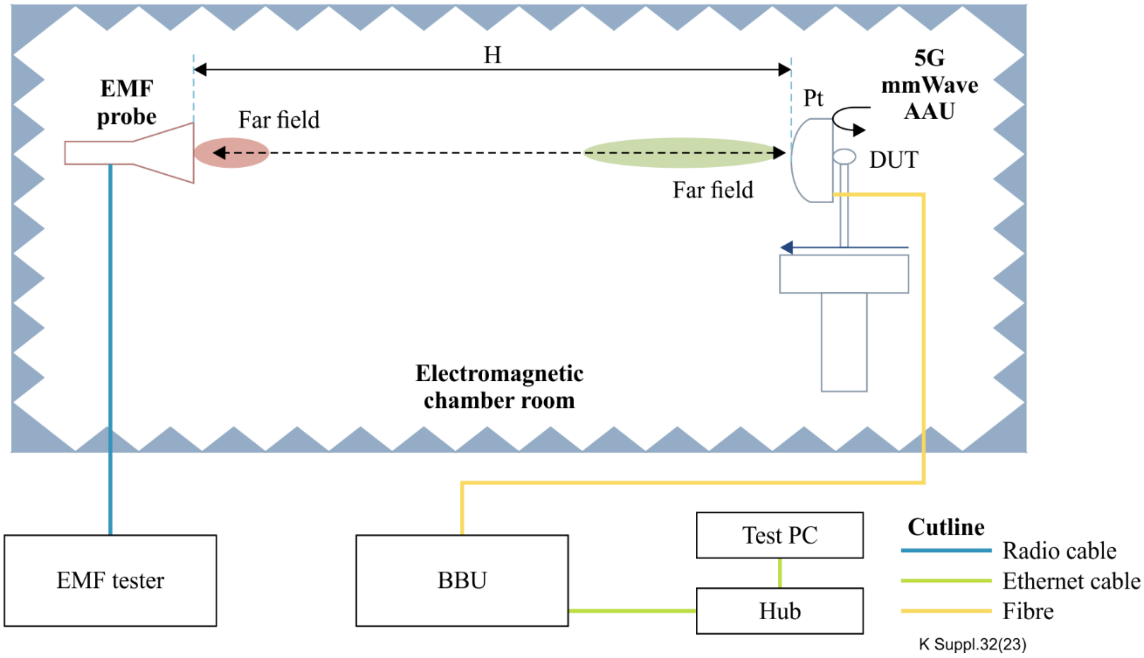

Figure 11-1 – Test layout for mmWave EMF radiation exposure level under OTA chamber

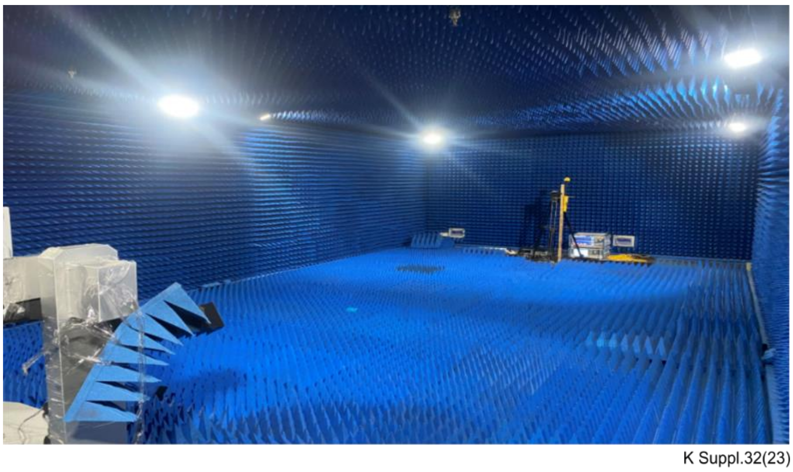

Figure 11-2 – Far-field OTA anechoic chamber

11.3 Measured 5G mmWave AAU base station parameters

The 5G mmWave AAU parameters are shown in Table 11-2 and the active antenna unit (AAU) is shown in Figure 11-3.

Table 11-2 – Parameters of the measured 5G mmWave AAU base station

AAU Type	Type 2-O
FR2 band (n258)	24.75~27.5 GHz
IBW (Instantaneous Bandwidth)	800 MHz
OBW (Occupied Bandwidth)	800 MHz
TR/TX	4T/4R
Antenna elements	768
Nominal EIRP	63.5~65 dBm

Table 11-2 – Parameters of the measured 5G mmWave AAU base station

TRP (Total Radiated Power)	34.5 dBm
Service beam scanning range (horizontal)	±60°
Service beam scanning range (vertical)	±20°
Service beam width (horizontal)	6.5°
Service beam width (vertical)	4.5°
Dimension	440×315×122 (mm)
Weight	16 kg

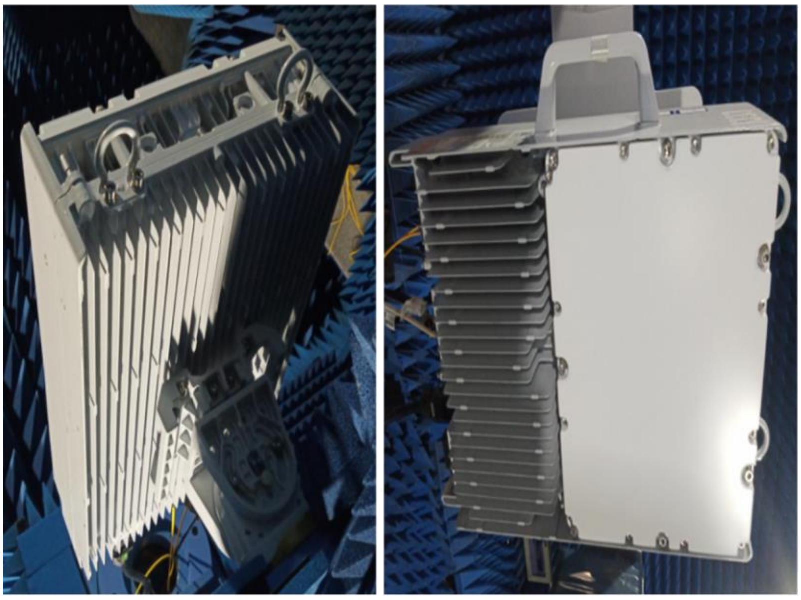

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Figure 11-3 – 5G mmWave AAU

11.4 Testing power configuration of the measured 5G mmWave AAU3

Configuration of maximum EIRP and super large downlink DDDSU (3D1U) frame structure conditions, ensure that the downlink rate remains stable at 3-4 Gbit/s to carry out the 5G mmWave AAU EMF exposure level test. Where:

1) AAU transmission condition: EIRP = 64.35 dBm (4 channels).
2) Test model configuration: TM3.1 according to [b-ETSI TS 138 141-1]
3) Bandwidth: 800M (4×200M), Sub-carrier interval SCS: 120 kHz.
4) Resource block: 528RB (4×132RB). Service data frame format: 3D1U (DDDSU).

11.5 Test points setup and distribution

In the OTA chamber, the mmWave AAU base station is fixed, and the mmWave beam H0V0 (normal direction) is facing the receiving antenna of the EMF radiation tester. The distance between the base station AAU and the EMF radiation tester receiving probe is 7 m.

When measuring, rotate the turntable and change the AAU angle: horizontal direction to 1° for the interval, vertical direction to 0.5° for the interval, set different test points, and then respectively measure EMF values of different points. The testing points setup and distribution diagram is shown in Figure 11-4.

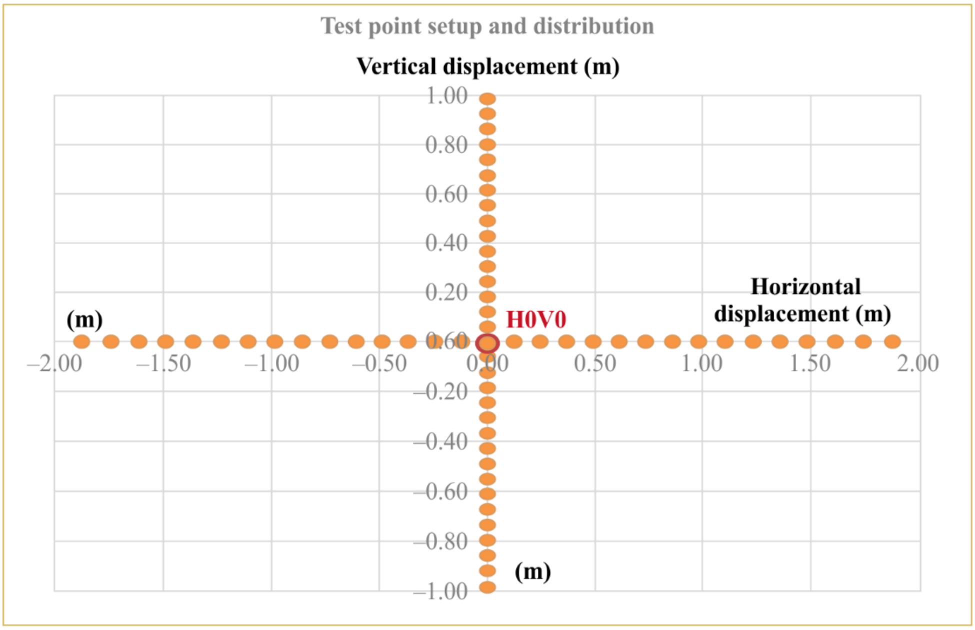

Figure 11-4 – Testing points setup and distribution diagram

11.6 Test procedure

The test procedure includes the following main steps:

1) Preheating

AAU and test instrument should be fully preheated for 30 minutes, work normally, and connect the ground wire. The required test instruments meet the measurement requirements and all line losses have been compensated.

2) Configuration

Configure a 5G (FR2) NR cell, and complete AC calibration. On the monitoring console of the FR2 network system, adjust the 5G NR power to the rated output power and set the beam to point in the direction of normal H0V0, and send the testing data, all AAU antennas are transmitting.

3) Finding the maximum EIRP

The remote horn was set to receive in the horizontal polarization direction, and the frequency spectrum analyser connected to the remote horn was used to measure the output power of the AAU transmission period, and the AAU turntable is rotated to find the maximum position and direction of the EIRP.

4) Starting testing

In the EIRP maximum position and direction, the fixed EMF radiation tester receiving antenna position, adjust the direction of AAU turntable and beam pointing. Measure and record the EMF radiation values at different points in accordance with the test points described in Figure 11-4.

The EMF tester and its probe are placed in an OTA chamber, in order to conveniently test and record through the external EMF tester control terminal (PC) to the real-time recording of measurement results. The control terminal communicates with the EMF tester through a fibre optic connection.

Figure 11-5 shows screenshots of EMF exposure level measurements of a 5G mmWave beam displayed on the test control terminal (PC).

a) Unit: V/m
(Electric field intensity)

b) Unit: mW/cm^2 or x1000 µ W/cm^2
(Power density)

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Figure 11-5 – Screenshots of EMF exposure level results displayed on the test terminal (PC)

11.7 mmWave beam RF-EMF exposure level measurement results

1) Horizontal beam width and EMF level

In the horizontal direction, the included angle on both sides of the beam where the radiation power drops by 3 dB, namely, the included angle between two half power points of the beam, is defined as the horizontal beam width.

The measurement results of the mmWave AAU's horizontal beam EMF radiation levels are shown in the Table 11-3 (positive axis direction) and Table 11-4 (negative axis direction).

NOTE – EIRP is set at the maximum, measuring points are 7 m away from AAU.

Table 11-3 – Horizontal beam EMF exposure level at positive axis direction

Positive axis direction (Beam direction: H0V0)			
Turntable direction		**EMF level**	
Horizontal (°)	**Displacement (m)**	**Electric field intensity E (V/m)**	**Power density S (W/m^2)**
0	0	31.43	2.620
1	0.12	30.64	2.490
2	0.24	25.78	1.763
3	0.37	19.85	1.045
4	0.49	16.13	0.690
5	0.61	12.7	0.428
6	0.74	7.66	0.156
7	0.86	3.18	0.027
8	0.98	2.52	0.017
9	1.11	4.05	0.044
10	1.23	5.83	0.090
11	1.36	6.21	0.102
12	1.49	4.85	0.062
13	1.62	3.01	0.024

Table 11-3 – Horizontal beam EMF exposure level at positive axis direction

Positive axis direction (Beam direction: H0V0)			
Turntable direction		**EMF level**	
Horizontal (°)	**Displacement (m)**	**Electric field intensity E (V/m)**	**Power density S (W/m²)**
14	1.75	1.48	0.006
15	1.88	1.56	0.007

Table 11-4 – Horizontal beam EMF exposure level at negative axis direction

Negative axis direction (Beam direction: H0V0)			
Turntable direction		**EMF level**	
Horizontal (°)	**Displacement (m)**	**Electric field intensity E (V/m)**	**Power density S (W/m²)**
0	**0**	**30.88**	**2.529**
−1	−0.12	28.82	2.203
−2	−0.24	24.27	1.562
−3	−0.37	20.55	1.202
−4	−0.49	17.82	0.842
−5	−0.61	12.98	0.447
−6	−0.74	7.2	0.138
−7	−0.86	3.48	0.032
−8	−0.98	2.81	0.021
−9	−1.11	4.41	0.052
−10	−1.23	5.75	0.088
−11	−1.36	5.22	0.072
−12	−1.49	3.74	0.037
−13	−1.62	2.55	0.017
−14	−1.75	1.36	0.005
−15	−1.88	2.33	0.014

In the OTA environment, it can be seen from Table 11-3 and Table 11-4, that the horizontal beam 7 metres away from the AAU has a maximum EMF exposure level of 2.620 W/m^2 (power density S), and that the corresponding electric field intensity E is 31.43 V/m.

By the definition of beam width, it can be seen that the measured horizontal beam width is about 6° (−3° ~ +3°), which is basically consistent with the nominal horizontal beam width of the AAU base station itself of 6.5°.

2) Vertical beam width and EMF level

In the vertical direction, the included angle on both sides of the beam where the radiation power drops by 3 dB, namely the included angle between the two half power points of the beam, is defined as the vertical beam width.

Measurement results of the vertical beam EMF radiation levels are shown in Table 11-5 (positive axis direction) and Table 11-6 (negative axis direction).

Table 11-5 – Vertical beam EMF exposure level at positive axis direction

Positive axis direction (Beam direction: H0V0)			
Turntable direction		**EMF level**	
Vertical (°)	**Displacement (m)**	**Electric field intensity E (V/m)**	**Power density S (W/m^2)**
0	0	30.41	**2.453**
0.5	0.06	29.14	2.252
1	0.12	26.31	1.836
1.5	0.18	23.69	1.489
2	0.24	20.45	**1.109**
2.5	0.31	16.5	0.722
3	0.37	12.35	0.405
3.5	0.43	8.65	0.199
4	0.49	4.79	0.061
4.5	0.55	1.69	0.008
5	0.61	1.75	0.008
5.5	0.67	3.71	0.037
6	0.74	5.15	0.070
6.5	0.8	5.82	0.090
7	0.86	5.95	0.094
7.5	0.92	5.47	0.079

Table 11-6 – Vertical beam EMF exposure level at negative axis direction

Negative axis direction (Beam direction: H0V0)			
Turntable direction		**EMF level**	
Vertical (°)	**Displacement (m)**	**Electric field intensity E (V/m)**	**Power density S (W/m^2)**
0	0	30.88	**2.403**
−0.5	−0.06	28.82	2.370
−1	−0.12	24.27	2.170
−1.5	−0.18	20.55	1.840
−2	−0.24	17.82	**1.450**
−2.5	−0.31	12.98	1.022
−3	−0.37	7.2	0.637
−3.5	−0.43	3.48	0.348

Table 11-6 – Vertical beam EMF exposure level at negative axis direction

Negative axis direction (Beam direction: H0V0)			
Turntable direction		EMF level	
Vertical (°)	Displacement (m)	Electric field intensity E (V/m)	Power density S (W/m^2)
−4	−0.49	2.81	0.161
−4.5	−0.55	4.41	0.054
−5	−0.61	5.75	0.011
−5.5	−0.67	5.22	0.014
−6	−0.74	3.74	0.039
−6.5	−0.8	2.55	0.065
−7	−0.86	1.36	0.081
−7.5	−0.92	2.33	0.079

According to Table 11-5 and Table 11-6, the vertical beam 7 metres away from the AAU has a maximum EMF exposure level of 2.453 W/m^2 (power density S), and the corresponding electric field intensity *E* is 30.41 V/m.

It also can be seen that the measured vertical beam width is about 4^o (−2^o ~ +2^o) which is basically consistent with the nominal vertical beam width of 4.5^o of the AAU base station itself.

11.8 Analysis of measurement results

1) 5G mmWave EMF level theoretical calculation results

When the service data frame format is DDDSU (3D1U), the maximum EMF exposure level S_H (power density) of AAU mmWave beam at H metres away from the normal direction can be calculated by equation (1):

$$S_H = (P / 4\pi H^2) \times 0.7 \text{ W/m}^2 \quad (1)$$

Where:

- S_H: Power density at the distant point H m in the normal direction of AAU beam (W/m^2)
- P: Maximum of the EIRP of AAU (W)
- H: Distance between AAU and EMF test point (m).

Considering the EIRP fluctuation of the AAU base station at the maximum transmitting power, two cases of EIRP are taken as 64.35 dBm and 63.5 dBm respectively.

Table 11-7 shows the different EMF level theoretical calculation values of an mmWave between 6~12 m away from the normal direction of the AAU FR2 base station.

Table 11-7 – EMF calculation values of mmWave between 6~12 m away from AAU

Distance H (m)	When: P=2723 W (EIRP=64.35 dBm)	When: P=2239 W (EIRP=63.5 dBm)
	S_H (W/m^2)	S_H (W/m^2)
6	4.213	3.465
6.9	3.186	2.620
7	3.096	2.545
7.6	2.626	2.159
7.9	2.430	**1.998**
8.2	2.256	1.855
8.7	**2.004**	1.648
9.4	1.717	1.412
10	1.517	1.247
11	1.257	1.031
12	1.053	0.866

2) Comparative analysis of measurement results and calculation values

According to the mmWave beam EMF measurement results shown from Table 11-3 to Table 11-6 in the OTA environment, 7 metres away from the AAU beam normal direction, the measured beam EMF level maximum (power density) is 2.620 W/m^2 (horizontal beam) or 2.453 W/m^2 (vertical beam). With the same AAU parameters, the theoretical calculated power density at 7 m is 3.096 W/m^2 (EIRP=64.35 dBm) or 2.545 W/m^2 (EIRP=63.5 dBm).

By comparing the actual measurement results in OTA free space and theoretical calculation results shown in Table 11-7, it can be seen that:

a) When taking EIRP=64.35 dBm:

The EMF measurement results at 7 metres and the calculation results at 7.6 metres basically match.

b) When taking EIRP=63.5 dBm:

The EMF measurement results at 7 metres and the calculation results at 6.9 metres basically match.

The above results show that under the same parameter conditions, although there is some error between the measured results and the calculated results, the error range is less than 16%. This error range is acceptable in view of the uncertainty in the measurement of mmWave high frequency characteristics.

Through comparative analysis, it can be shown that this test case study is successful, the measurement environment and measurement method are appropriate, and the measurement results are credible.

3) 5G mmWave EMF compliance and radiation safety boundary determination

According to China's national limit standard [b-GB 8702], the EMF exposure level related to the mmWave band is less than or equal to 2.00 W/m^2 (see Table 11-1). For the mmWave AAU base station in this case study, since the measurement results basically match the theoretical calculation results, it can be concluded from Table 11-7:

a) **When EIRP=64.35 dBm:** The safety boundary distance of mmWave AAU is about 8.7 m.

b) **When EIRP=63.5 dBm:** The safety boundary distance is about 7.9 m.

Therefore, when planning the large-scale construction of 5G mmWave base stations, the requirement of the mmWave radiation safety boundary distance should be taken into account. In the case of the 5G mmWave AAU, where the safety distance between the mmWave AAU and electromagnetic radiation environment sensitive targets such as houses, schools, hospitals, office buildings, factories and other buildings where the public live, work or study, is not less than 8.7 metres, the EMF level under the 5G mmWave network can conform to the requirements of the limit standard, and is also safe and controllable on the whole.

11.9 Conclusion

This case study tested and evaluated the EMF radiation exposure level of 5G mmWave AAU in an OTA environment, and the test results closely matched the theoretical calculation results. According to the requirements of China's mmWave EMF radiation limit, the safety boundary distance of the FR2 base station was determined to be about 8.7 m, which is an acceptable safety boundary distance for the mmWave networking, basically it will not affect the large-scale construction of 5G mmWave base stations in the future.

12 Case study of 5G-NR BS EMF measurement by applying the zero-span and code select method

12.1 Background

Like other countries, Korea limits RF-EMF levels emitted from mobile communication base stations within the human protection standard. Korea strictly manages the RF-EMF of BS as a policy. It is mandatory to evaluate the RF-EMF for BSs including 5G-NR services installed in residential and commercial areas. The RF-EMF assessment method of 5G-NR BS has been newly proposed and is under discussion to prepare for the revision of [IEC 62232]. Korea has been applying the proposed RF-EMF assessment method since 2019. The BSs of 5G-NR services began to be installed in 2019, and the RF-EMF was measured for about 170,000 BSs by 2022. In order to assess the RF-EMF of the 5G-NR BS, the synchronization signal block (SSB) signal which is used to synchronize the BS and the user equipment (UE) must be measured first according to the proposed measurement method. There are two measurement methods for SSB signal level: zero-span and code-select. Theoretically, there should be no difference in the RF-EMF measurement results when applying the two methods for one BS. However, there was a difference in the measurement result between two methods due to the environmental variation at the measurement point as it was a multiple BSs environment. Therefore, this document discusses the difference in RF-EMF measurements results according to the two methods for the 5G-NR BSs in Korea.

12.2 RF-EMF measurement method of 5G-NR BS

Figure 12-1 shows the RF-EMF measurement procedure of a 5G-NR BS. The measurement point is chosen where the RF-EMF level is the highest which satisfies the line of sight (LOS) with the BS's antenna. Figure 12-2 shows the RF-EMF measurement point selection procedure and a photo of the actual measurement place as an example, and the detailed conditions to choose the measurement points are as follows:

– RF-EMF is measured for 6 minutes each at the height of 1.1 m, 1.5 m and 1.7 m from the ground where the RF-EMF measurement value is the highest from the BS as shown in Figure 12-2(a).

– Thus, the value for RF-EMF assessment is obtained by calculating the spatial average of the measurement results at each indicated height.

The RF-EMF of the 5G-NR BS is assessed with the maximum value obtained by applying the extrapolation method to the measured SSB signal level. Thus, the SSB level should be measured first for compliance assessment. The SSB is a signal transmitted periodically repeated within the downlink symbol frame of the 5G-NR BS. Each beam emitted by the 5G-NR BS has an SSB signal, which is used to synchronize with a UE. Figure 12-3 shows a schematic conceptual diagram of SSB.

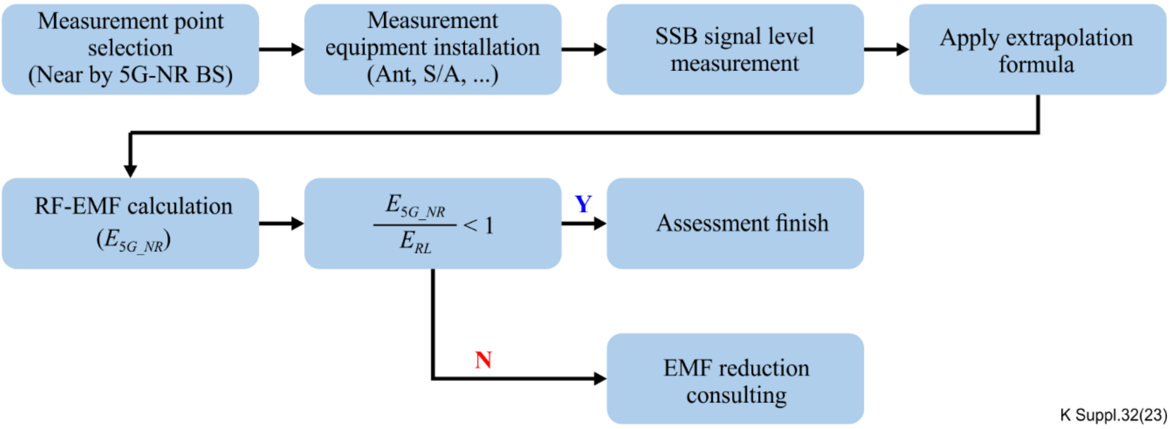
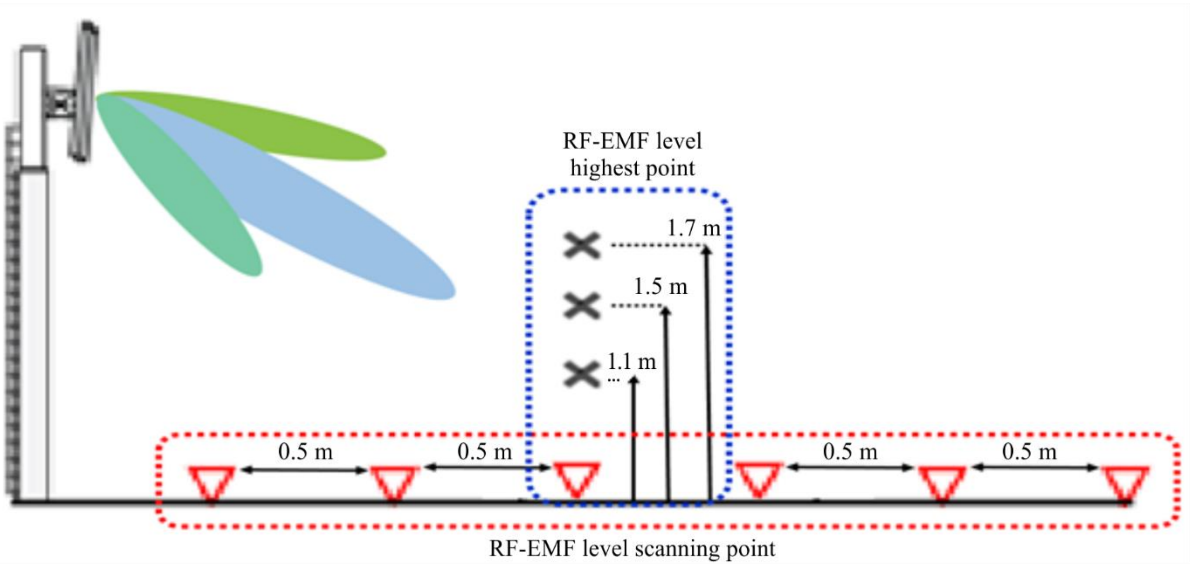


Figure 12-1 – RF-EMF measurement procedure of a 5G-NR BS



a) RF-EMF measurement point selection procedure for 5G-NR BS

b) 5G-NR BS RF-EMF actual measurement environment

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Figure 12-2 – RF-EMF measurement point selection procedure for 5G-NR BS and actual environment

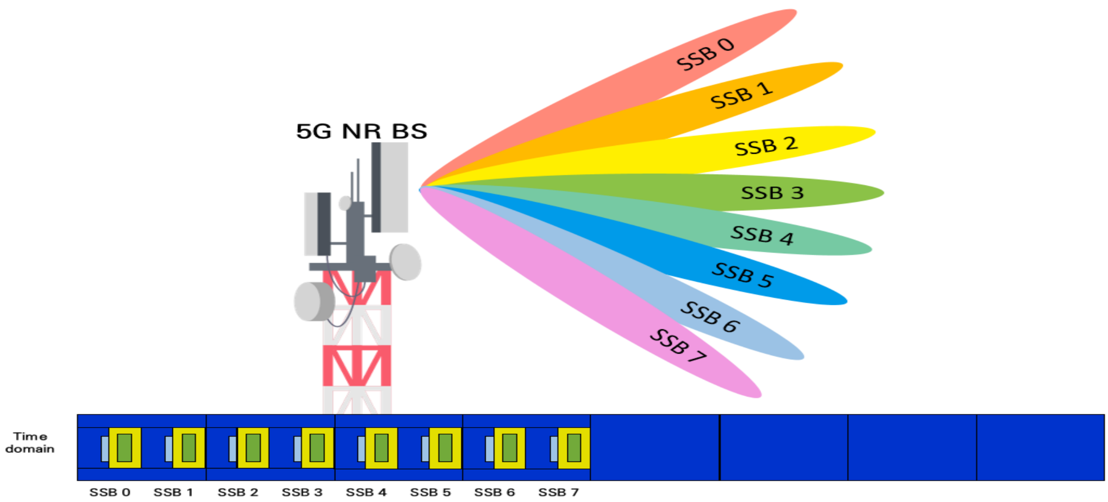

Figure 12-3 – SSB signal from the 5G NR BS and the schematic structure in time domain

The first step in determining the RF-EMF level of a 5G-NR BS is to measure the BS's SSB signal. After measuring the SSB signal level, the RF-EMF is evaluated with an extrapolation method under the assumption that the SSB signal level is evenly distributed throughout the frequency band used by the 5G-NR BS which is shown in [IEC 62232].

Measuring the SSB level is an important factor in determining RF-EMF strength level of a 5G-NR BS. There are two measurement methods for the SSB signal from the BS: the zero-span method and the code-select method. As of recently, spectrum analysers capable of measuring RF-EMF of 5G-NR BS are usually equipped with the SSB signal measurement functions. In the code-select method, it is easy to target and measure a specific BS in an environment where several BSs exist around the measurement point, which the zero-span method cannot perform. The Rep. of Korea allows both methods for RF-EMF compliance assessment of 5G-NR BS. This document compares the RF-EMF measurement results of 5G BSs in Korea where both methods are applied.

12.3 Measurement method of SSB level

The zero-span method measures the downlink signal of the 5G-NR BS in the time domain and measures the level of the SSB signal placed in front of the packet data. This method has the advantage of being able to measure without additional configuration on a traditional spectrum analyser. However, this method cannot separate multiple beams of a 5G-NR BS, and cannot separate and measure a specific BS if there are several BSs around the measurement point.

The code-select method requires a demodulation mode function in the measurement equipment that can apply for the downlink signal of the 5G-NR BS to obtain various information from the measured demodulated signal. This method can easily separate the SSB signal from the BS. In particular, each SSB level for several beams emitting from BSs can be separately measured and the SSB signal level of a BS can be accurately separated from multiple adjacent BSs.

Figure 12-4 shows a situation where there are two 5G-NR BSs around the measurement point. Each BS has a unique physical cell ID (PCI) number, and the code-select method can separately measure the SSB level according to each PCI number. On the other hand, the zero-span method cannot separate the SSB according to each PCI number. The zero-span method just can measure the levels in time domain.

Table 12-1 compares the differences between zero-span and code-select methods. Both methods can be applied to measure the RF-EMF of a 5G-NR BS.

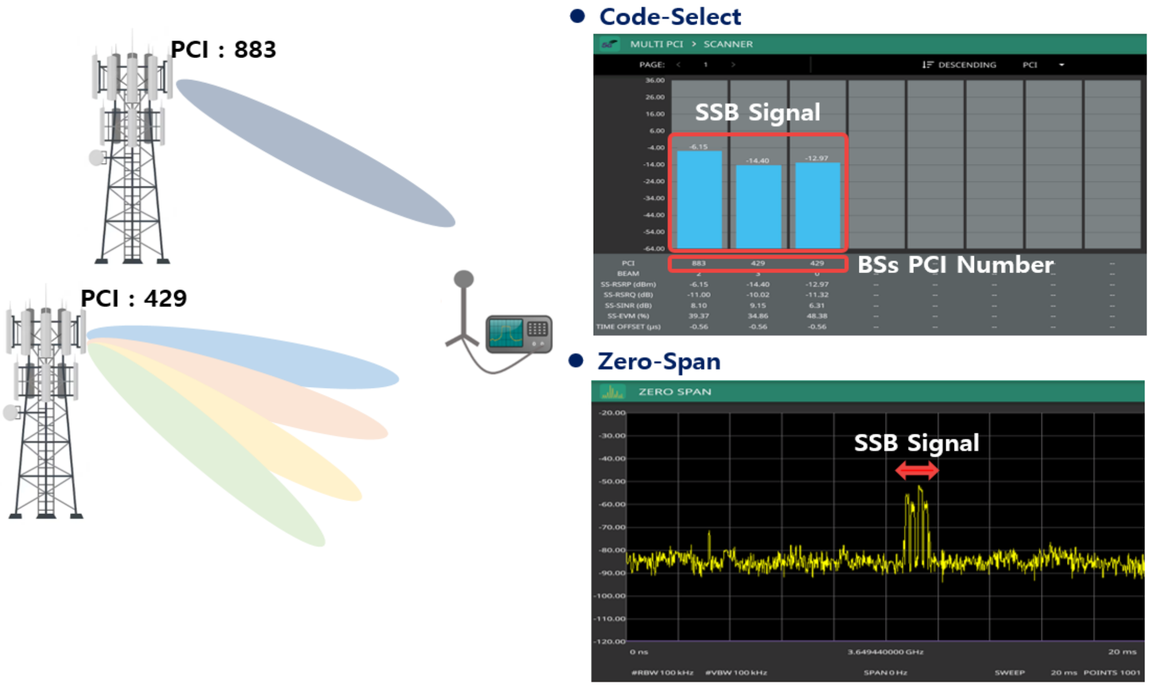

Figure 12-4 – SSB level measurement method, code-select and zero-span comparison example

Table 12-1 – Comparison of SSB level measurement methods

Index	Zero-span	Code-select
Requirement function	Measure maximum signal traffic	Synchronize with BS
SSB measurement	Measure the time-domain signal	Measure by 5G-NR demodulation
Measurement for multiple BSs environment	Measure the maximum level	Measure the signal of the selected BS

12.4 RF-EMF measurement results for 5G-NR BS in Korea

Table 12-2 and Figure 12-5 show the RF-EMF calculated mean value from the measurement results of 5G-NR BS from 2019 to 2022. In the initial stage of 5G service, the number of 5G-NR BSs was few, thus, there was little difference in the measurement results between the two methods as shown in Figure 12-5. However, the number of 5G BSs has increased in the past two years, from 2021 to 2022, hence, the difference in the measurement results between the two methods was evident. The strength of the RF-EMF measurement result with the code-select method is lower than zero-span method. This can be presumed due to the difference in their functions of which the code-select method can separate signals from multiple BSs and measure SSB signals of a specific BS, but the zero-span method measures the overlapping SSB signals of multiple BSs in the time domain from multiple BSs.

Table 12-2 – The 5G-NR RF-EMF measurement results using two methods [V/m]

Area	Method	2019	2020	2021	2022
Nationwide	Zero-Span	1.48	1.75	2.19	2.73
	Code-Select	1.49	1.75	1.62	1.71
Seoul	Zero-Span	1.42	1.56	1.82	3.21
	Code-Select	1.54	1.53	1.65	1.89

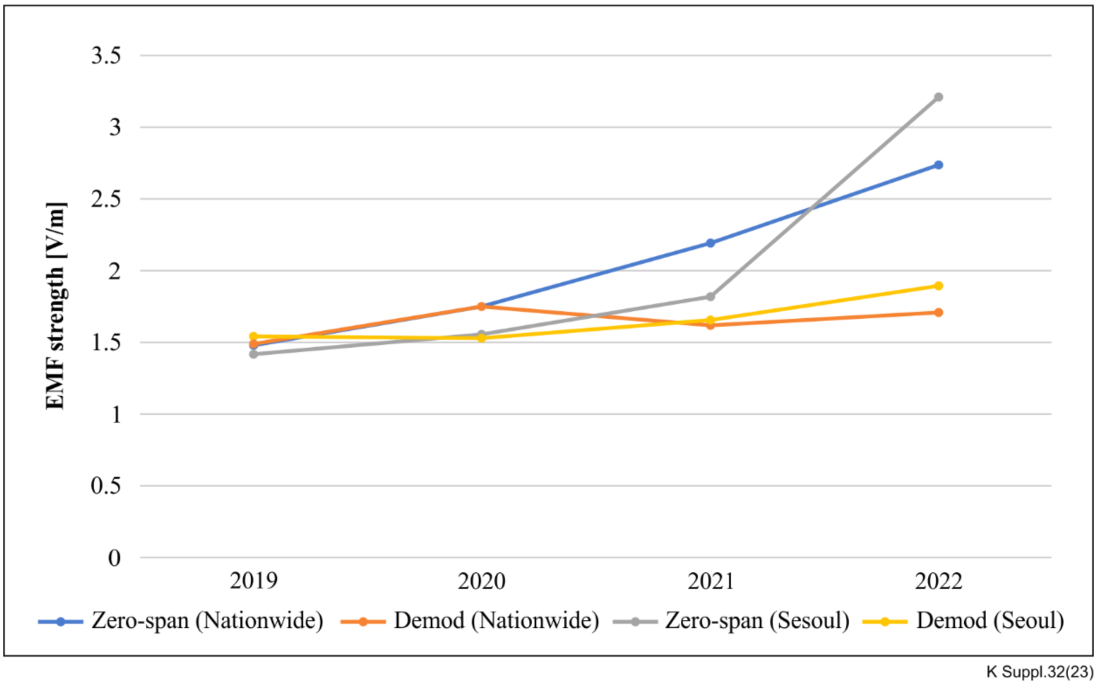

Figure 12-5 – The measurement results graphed with the data of Table 12-2

12.5 Comparative analysis of RF-EMF according to SSB measurement method

As shown in Table 12-2 and Figure 12-5, there was no significant difference in the measurement results of 2019 and 2020 obtained by applying two assessment methods in the early years of 5G-NR BS installation. However, a significant difference appeared in 2021 and 2022, as the number of 5G-NR BS increased. In order to compare the difference in RF-EMF measurement results of 5G-NR BS according to the SSB level measurement method, the measurement data from 2021 to 2022 was analysed where the difference was evident. The number of 5G-NR BSs installed in residential and commercial areas from 2021 to 2022 is shown in Table 12-3. In Korea, the number of measurement data using the zero-span method was about 2.5 times greater than the code-select method. To analyse the two methods statistically, 500 data were randomly extracted from each of the two methods for the residential and commercial areas.

Table 12-3 – Total number of 5G-NR measurements in Korea

Method	Residential area	Commercial area
Zero-Span	19,948	12,545
Code-Select	663	561

Table 12-4 and Figure 12-6 show the results of analysis by randomly extracting 500 data from 2021 to 2022. In both residential and commercial areas, the zero-span method has a relatively larger deviation than the code-select method. Although the two methods were applied in similar measurement environments for the same period, the results were different. Korea analysed the data measured in Seoul to consider how the large numbers and high density of BSs in Seoul as compared to other regions affect the measurement results, as shown in Figure 12-7. The measurement results of Seoul were slightly higher than the national average, and the zero-span showed a slightly higher level of deviation. This trend is similar to the results shown in Figure 12-7.

12.6 Summary

In the initial stage of installation where the density of 5G-NR BSs is low, the difference in RF-EMF assessment results between the zero-span and code-select methods was not significant, but as the number of BSs and density increased, the results between the two methods showed a significant difference. Through this, it can be inferred that the BS density affects the 5G-NR BS RF-EMF assessment result. Therefore, when assessing the RF-EMF of the 5G-NR BS, it is deemed necessary to consider the assessment method according to the BS installation environment and the purpose of the assessment.

Table 12-4 – RF-EMF analysis after randomly extracting 500 data according to each method [V/m]

Index	Method	Residence		Commercial	
		Zero-Span	Code-Select	Zero-Span	Code-Select
Nationwide	Mean	1.96	1.31	2.85	2.01
	Median	0.73	0.69	1.49	1.19
Seoul	Mean	1.93	1.46	3.08	2.06
	Median	0.75	0.65	1.43	1.19

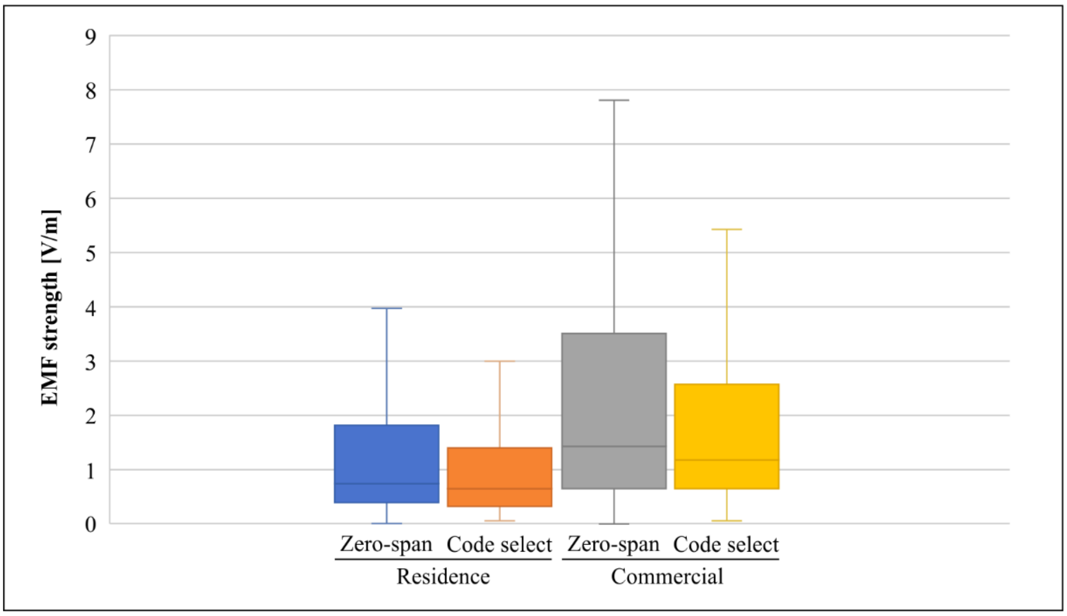

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Figure 12-6 – RF-EMF measurement results according to each method (Nationwide)

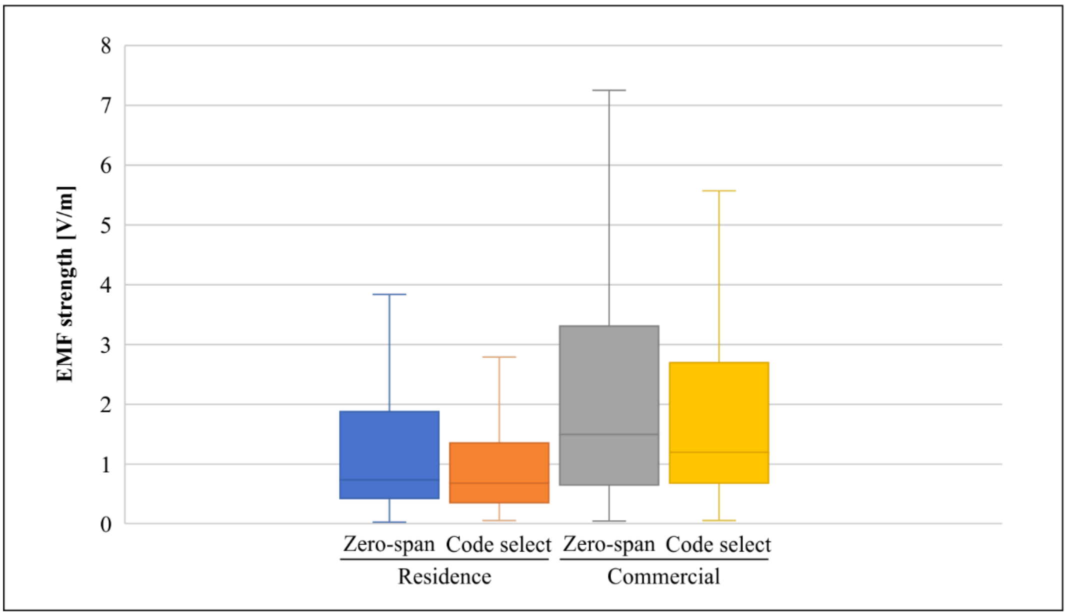

Figure 12-7 – RF-EMF measurement results according to each method (in Seoul)

Appendix I

Technical information supporting the case study on a 5G macro BS site with massive MIMO *in-situ* RF exposure assessment

I.1 Description of the *in-situ* RF exposure measurement method for 5G mMIMO BS

See clause 9.

I.1.1 Environmental condition for measurement

Weather conditions, e.g., rain, temperature, meet the operating requirements of the measurement instrument.

I.1.2 General requirements for measurement instrument

The working performance of the measurement system should meet the requirements of RF-EMF to be measured. The measurement instrument produces readings as root mean squares, averaged over a continuous period of 6 minutes. The measurement instrument also meets the following requirements.

– During measurement, a frequency selective electromagnetic radiation measurement instrument is used, the measurement frequency is selected as the downlink frequency band when the 5G BS transmitting antenna under test is working.

– When measuring RF exposure of 5G and other network system BSs at the same site, a frequency selective electromagnetic radiation measurement instrument has means to conveniently measure different frequency ranges in a sequence.

– When measuring, the measurement system uses an isotropic probe, which meets index requirements in Table I.1. If a non-isotropic probe is used, the influence of antenna directivity is considered, and the antenna factor and other parameters are synthesized in result processing; the detection direction and polarization is adjusted in the measurement until the maximum field intensity is measured.

– To support the instrument, a tripod constructed of non-conductive materials that are not susceptible to moisture is used.

I.1.3 Specifications of the measurement instrument

Table I.1 lists the basic specifications of a 5G frequency selective measurement instrument.

Table I.1 – Basic specifications of a frequency selective measurement instrument (see [IEC 62232])

Item	Specification
Frequency response	900 MHz~3 GHz, ≤ ±1.5 dB
	< 900 MHz or > 3 GHz, ≤ ±3 dB
Dynamic range	> 60 dB
Probe detection limit	The lower detection limit of the probe is < 7 × 10^{-6} W/m^2 (0.05 V/m) The upper detection limit was ≥ 25 W/m^2 (100 V/m)
linearity	≤ ±1.5 dB
Frequency error	< 10^{-3} Orders of magnitude of the measured frequency
Isotropic	< 900 MHz, isotropic < 2 dB 900 MHz~3 GHz, isotropic < 3 dB > 3 GHz, isotropic < 5 dB

I.1.4 Information collection

Before measurement, basic information about the 5G BS under test is collected, including the following:

– Physical site information: BS name, operator, construction site, latitude and longitude coordinates, transmission frequency range, type of antenna bracket, number of antennas, operation status, antenna height from the ground, etc.

– 5G BS parameter information: Collected according to monitoring purposes and needs, including Tx model, rated maximum power, actual transmitted power, antenna gain, average load, antenna tilt angle (mechanical tilt angle plus electronic tilt angle), antenna lobe width (horizontal width, vertical width), antenna direction diagram, etc.

– The same basic information is collected for BSs with other network systems at the same site.

I.1.5 Measurement factor

The measured variable of the electromagnetic radiation environment of a 5G BS is RF EMF, and the metric is the power density.

I.1.6 Measurement point selection

The measurement point should be arranged in the coverage range of the beams of the 5G BS antenna:

– When measuring outside a building, the measurement point is located at the sensitive target of the electromagnetic radiation environment within the coverage range of the BS antenna, especially the area with public activities in the direction of its main lobe, and the nearest place where the public lives, works or studies from the antenna is prioritized. However, it is not arranged in places that need to be reached by means of tools (such as ladders) or special means (such as climbing).

– When measuring in a building, the measurement point can be arranged in the window (balcony) position towards the BS antenna, and the probe tip of the measuring instrument is within the window frame (balcony) interface, or other indoor positions. In addition, the distance between the probe of the measuring instrument and the equipment such as household appliances is ≥1 m.

I.1.7 Measurement height

The probe of the measurement instrument is 1.5 m to 2.0 m above the ground (or the base plane). Another measurement height can also be selected according to different purposes and indicated in the measurement report.

I.1.8 Measurement of working conditions and 5G user equipment

During measurement, the 5G BS under test operates under normal working conditions, a 5G UE is connected to the 5G BS in at least one of the typical application scenarios mentioned in clause 9.1. That is to say, the EMF of a 5G BS is measured during downlink traffic and no load is avoided.

During measurement, the instrument probe is placed on a bracket, the distance between the probe tip and the operator's trunk is ≥ 0.5 m, the distance between the probe and 5G UE is maintained within the range 1 m to 3 m.

In addition, it is necessary to avoid or minimize the interference of other accidental electromagnetic radiation sources and the influence of the leakage current of the measuring instrument bracket.

I.1.9 Measurement readings

The time for each measurement point is ≥ 6 minutes, over which time the measured average value of the power density read from the instrument is the result.

According to the statistics of a large number of measurement cases, in most cases, the average power density reading on the instrument tends to be stable after continuous measurement for about 1 minute. Therefore, a 1 minute measurement time can be used when appropriate as a simple and feasible alternative to one of 6 minutes according to measurement needs.

NOTE – The integral value refers to the sum of the power density values contributed by all frequency points in the measured frequency band.

I.1.10 Information record

During measuring, to ensure the accuracy and traceability of measurement information, the following information is recorded:

a) relevant information about the 5G BS under test collected in clause I.1.4;

b) environmental temperature, relative humidity and weather conditions, as well as measurement date, start and end time, measurement personnel, etc.;

c) measurement frequency range, instrument and probe model, including their calibration or verification certificate numbers, if any.

d) the selected application scenarios, models and quantities of 5G UE;

e) a schematic diagram of the *in-situ* measuring points and the marked location of 5G BS antenna, measurement points and other known electromagnetic radiation sources;

f) the name (or latitude and longitude) of the measurement point, the vertical and horizontal distance between the measurement point and the 5G BS transmitting antenna, the measurement data, and a saved spectrum distribution map.

NOTE – Clause I.4 provides the content and format of the *in-situ* measurement records for reference.

I.1.11 Measurement quality assurance

In order to ensure the reliability and accuracy of measurement data, the following quality assurance measures are taken:

a) The selection of measurement points is representative and conforms to the specifications of clause I.1.6.

b) The measurement instrument (including probe) is certified or calibrated regularly and used within the validity period of the certificate. The instrument is also checked before and after measurement to ensure that the instrument is in normal working condition.

c) Interference factors, including those due to humans and the environment, are excluded during measurement. The elimination of abnormal data and data processing of measurement results are handled according to statistical principles.

d) A complete measurement file is established.

I.2 Application scenarios selection

Case studies on 5G mMIMO *in-situ* RF exposure presented in clause 9 were conducted in three application scenarios with traffic rates in different downlink speed ranges: high, medium and low.

I.2.1 High-speed downlink scenarios

The application scenarios with downlink speeds >400 Mbit/s presented in the case studies of clause 9 are designated as high-speed scenarios. The strictest application is the eMBB scenario, in which the beam of 5G electromagnetic radiation is usually strong. It is more representative and significant to evaluate whether the EMF measurement results meet the standard limit requirements.

High-speed downlink scenarios lasting 6 minutes can be applied in different ways, as long as the rate is consistent and stable.

Example of a high-speed downlink application scenario

According to clause I.1.9, the *in-situ* RF exposure measurement result is the average value over any continuous period of 6 minutes. A 6 minute eMBB scenario with high-speed downlink > 400 Mbit/s can be achieved using a wireless network performance testing application, which ensures a stable and continuous connection between the 5G UE and the measured 5G BS without interruption for any period of time, and a downlink rate that can be maintained at 400 Mbit/s to 1 200 Mbit/s.

– The measurement layout for 5G EMF over 6 minutes with service in high-speed downlink scenarios is shown in Figure I.1. This measurement case requires two terminals, because the working bandwidth of the 5G BS shared by China Telecom and China Unicom is 200 MHz (between 3 400 MHz and 3 600 MHz), among which 100 MHz (between 3 400 MHz and 3 500 MHz) is used by China Telecom users, and the other 100 MHz (between 3 500 MHz and 3 600 MHz) is used by China Unicom users. The EMF of the shared 5G BS in 200 MHz working state is measured by two terminals at the same time via high-speed downlink.

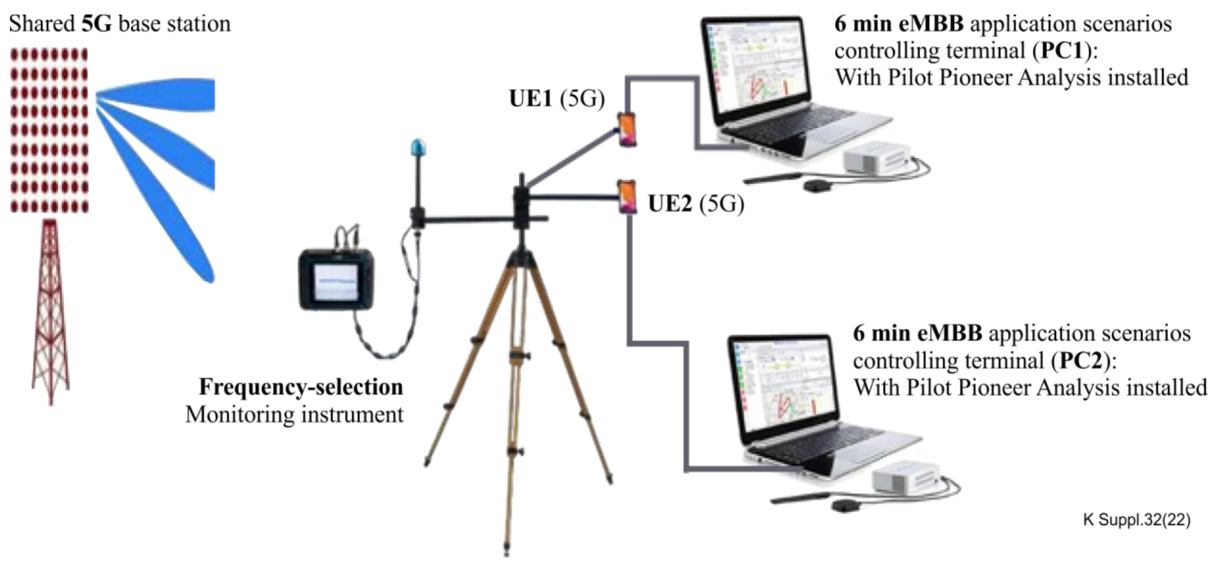

Figure I.1 – Measurement layout of 5G EMF for 6 min with service in high-speed scenarios

– Figure I.2 is a screenshot of a wireless network performance testing application generating a high-speed downlink.

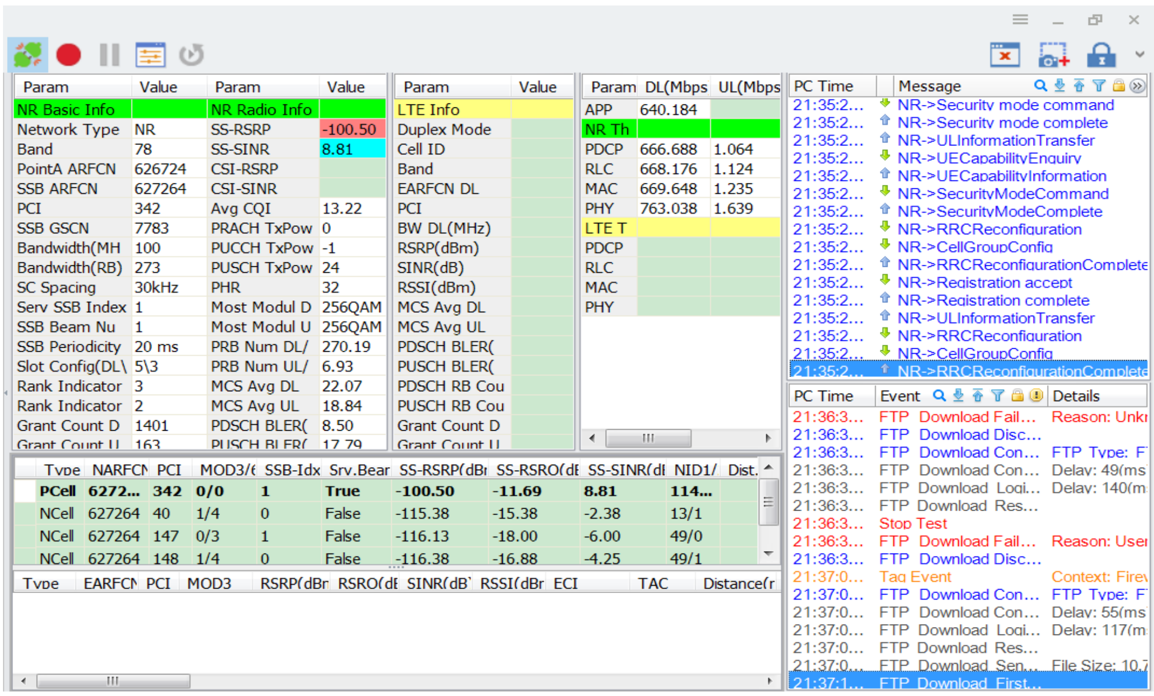

Figure I.2 – Screenshot of wireless network performance testing application for high-speed downlink

I.2.2 Medium-speed downlink scenarios

The application scenarios with downlink speed between 100 Mbit/s and 400 Mbit/s presented in the case studies of clause 9 are defined as medium-speed scenarios.

4K/8K video download or live video can also be selected to achieve medium-speed application scenarios (downlink rate 100 Mbit/s to 400 Mbit/s), such as Youku Video APP or Yahoo Live APP.

I.2.3 Low-speed downlink scenarios (common and daily application scenarios)

Application scenarios with downlink speeds < 100 Mbit/s presented in the case studies of clause 9 are defined as low-speed scenarios.

In fact, they are the most common scenarios used by people in daily life, such as browsing websites, reading news, instant chatting, virtual shopping, playing small videos and social media apps.

I.3 Comparison of the RF exposure limits of 5G wireless networks

[b-GB 8702] specifies limits of RF exposure. The RF exposure level around all constructed BSs must meet this standard requirement before a BS can be put into normal operation.

The public RF-EMF exposure limit requirements of 5G communication frequency band specified in [b-GB 8702], [b-ICNIRP] and [b-IEEE C95.1] guidelines are shown in Table I.2.

Table I.2 – RF-EMF limit standard requirements of FR1 band (< 7.125 GHz) for 5G (sub 6G) of China's four major operators

China operator	Band number	5G (sub 6G) Working frequency band	Power density *S* (W/m^2) / E-field (V/m)	
			[b-GB 8702]	[b-ICNIRP]/ [b-IEEE C95.1]
China Telecom	n1	1 920-1 940/ 2 110-2 130 MHz	0.4 W/m^2 12.3 V/m	10 W/m^2 61.4 V/m
	n78	3 400-3 500 MHz	0.47 W/ m^2 13.3 V/m	10 W/m^2 N.A.
China Unicom	n1	1 940-1 965/ 2 130-2 155 MHz	0.4 W/m^2 12.3 V/m	10 W/m^2 61.4 V/m
	n78	3 500-3 600 MHz	0.48 W/m^2 13.5 V/m	10 W/m^2 N.A.
China Mobile	n41	2 515-2 675 MHz	0.4 W/m^2 12.3 V/m	10 W/m^2 N.A.
	n79	4 800-4 900 MHz	0.65 W/m^2 15.4 V/m	10 W/m^2 N.A.
China Radio & Television	n28	703-743/758-798 MHz	0.4 W/m^2 12.3 V/m	3.99 W/m^2 38.8 V/m
	n79	4 900-5 000 MHz	0.67 W/m^2 15.6 V/m	10 W/m^2 N.A.

It can be seen from Table I.2 that the maximum power density of 5G (sub 6G) BS working in the FR1 band specified in [b-GB 8702] is 0.4 W/m^2 to 0.67 W/m^2.

According to [b-ICNIRP] and [b-IEEE C95.1], the maximum limit of RF exposure (power density) for 5G BSs is 10 W/m^2.

The current RF exposure limit of 5G BSs in China is 15 to 20 times stricter than other countries that adopt international limit standards.

I.4 Basic information record form

Table I.3 is a basic information record form of the 5G *in-situ* RF exposure measurement.

Table I.3 – Basic information record form

Basic information			
BS name		Operator	
Construction site		Transmitting frequency range	
Height from BS antenna to the ground		Type of antenna support	
Antenna number		Operating state	
Measurement conditions			
Date and time of measurement		Model of measuring instrument	
Weather conditions		Measuring instrument number	
environment temperature		probe model	
Relative humidity		probe number	
Measurement frequency range		Calibration certificate number of measuring instrument and probe	
BS EMF measurement point position diagram			
			

I.5 Measurement result record form

Table I.4 is a measurement result record form of the 5G *in-situ* RF exposure measurement.

Table I.4 – Measurement results record form

<table>
<tr><th colspan="11">Measurement results</th></tr>
<tr><th rowspan="2">S/N</th><th rowspan="2">Name of measurement point (or latitude and longitude)</th><th colspan="2">Distance from the BS antenna</th><th rowspan="2">Application scenarios</th><th colspan="2">Transmitting antenna</th><th colspan="2">5G UE</th><th rowspan="2">Power density (W/m^2)</th></tr>
<tr><th>Vertical</th><th>Horizontal</th><th>Operator</th><th>Downlink frequency band</th><th>Model</th><th>quantity</th></tr>
<tr><td></td><td></td><td></td><td></td><td>□ Data transmission
□ Video interaction
□ Game entertainment
□ Virtual shopping
□ Smart medical
□ Industrial application
□ Internet of vehicle
□ Other____</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>□ Data transmission
□ Video interaction
□ Game entertainment
□ Virtual shopping
□ Smart medical
□ Industrial application
□ Internet of vehicle
□ Other____</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>□ Data transmission
□ Video interaction
□ Game entertainment
□ Virtual shopping
□ Smart medical
□ Industrial application
□ Internet of vehicle
□ Other____</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

I.6 5G base stations installation reference

There are two main installation locations of 5G BSs in China: a) single pole station; b) house roof station.

I.6.1 Single pole stations

The following images are typical examples of single pole stations.

K Suppl.32(23)

I.6.2 House roof station

The following images are typical examples of house roof stations.

K Suppl.32(23)

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