International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

Series K
Supplement 26
(05/2021)

SERIES K: PROTECTION AGAINST INTERFERENCE

ITU-T K.114 – Analysis of electromagnetic compatibility requirements and test methods of 5G active antenna system base stations

ITU-T K-series Recommendations – Supplement 26

Supplement 26 to ITU-T K-series Recommendations

ITU-T K.114 – Analysis of electromagnetic compatibility requirements and test methods of 5G active antenna system base stations

Summary

The use of the active antenna system (AAS) is widespread within communication systems and vertical industries. Its main benefit is higher beam-forming gain, which can overcome the high path loss of higher carrier frequency. For the introduction of AAS, especially the integrated antenna array, special attention should be paid to corresponding electromagnetic compatibility test configuration and measurement methods. Radiated immunity, as an example, will increase dramatically as the antenna array gain cannot be distinguished. Supplement 26 to K-series Recommendations also discusses other technical issues such as the radiated immunity test, communication link establishment, performance assessment, and the electromagnetic field exposure problem for test personnel.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T K Suppl. 26	2021-05-20	5	11.1002/1000/14755

Keywords

5G, AAS, NR, EMC.

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

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ITU-T K.114 – Analysis of electromagnetic compatibility requirements and test methods of 5G active antenna system base stations

1 Scope

This Supplement aims to propose special electromagnetic compatibility test methods for the 5G active antenna system (AAS) base station. It includes the following technical requirements.

Test conditions for 5G AAS base stations are described; exclusion bands for the radiated immunity test, performance assessment such as throughput or error vector magnitude (EVM) and performance criteria for immunity tests are also described.

This Supplement does not describe the specific testing levels to be applied to 5G AAS base stations in different environments, such as telecommunication centres, customer premises and outdoor plants. The testing levels for 5G AAS base stations are consistent with [ITU-T K.114].

2 References

[ITU-T K.114]	Recommendation ITU-T K.114 (2015), *Electromagnetic compatibility requirements and measurement methods for digital cellular mobile communication base station equipment*.
[ITU-R SM.329]	Recommendation ITU-R SM.329 (2012), *Unwanted emissions in the spurious domain*.
[3GPP TS 38.104]	3GPP TS 38.104 (2021), *NR; Base station (BS) radio transmission and reception.*
[3GPP TS 38.113]	3GPP TS 38.113 (2021), *NR; Base station (BS) Electromagnetic Compatibility (EMC).*
[3GPP TS 38.141-1]	3GPP TS 38.141-1 (2021), *NR; Base station (BS) conformance testing Part 1: Conducted conformance testing*.
[3GPP TS 38.141-2]	3GPP TS 38.141-2 (2021), NR; *Base station (BS) conformance testing Part 2: Radiated conformance testing*.
[ETSI EN 301 489-1]	ETSI EN 301 489-1 (2017), Electromagnetic Compatibility (EMC) *standard for radio equipment and services; Harmonised Standard covering the essential requirements of article 3.1(b) of the Directive 2014/53/EU and the essential requirements of article 6 of the Directive 2014/30/EU; Part 1: Common technical requirements*.
[ETSI EN 301 489-50]	ETSI EN 301 489-50 V2.2.0 (2017), *Electromagnetic compatibility (EMC) standard for radio equipment and services; Part 50: Specific conditions for cellular communication base station (BS), repeater and ancillary equipment*.
[IEC CISPR 16-2-3]	CISPR 16-2-3 (2019), *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-3: Methods of measurement of disturbances and immunity – Radiated disturbance measurements.*
[IEC CISPR 32]	CISPR 32 (2015), A1 (2019), *Electromagnetic compatibility of multimedia equipment – Emission requirements*.
[IEC 60050-161]	IEC 60050-161(2017), *International Electrotechnical Vocabulary (IEV) – Part 161: Electromagnetic compatibility*.

[IEC 61000-4-3] IEC 61000-4-3 (2020), *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 active antenna system (AAS) [ITU-T K.114]: A base station system which combines an antenna array with an active transceiver unit array. An AAS may include a remote/radio distributed unit or network.

3.1.2 ancillary equipment [ITU-T K.114]: Equipment (modules or apparatus), as the part of main system, used in connection/conjunction with radio receiver or transmitter units to assist the base station to work normally, or to provide the additional operational features, e.g., supervisory control, backhaul connection, cooling control, antenna sector control. It could not work stand-alone independently of main system.

3.1.3 base station equipment [ITU-T K.114]: A base station is a network element in radio access network, responsible for radio transmission and reception in one or more cells to or from the mobile devices. A base station can have an integrated antenna or be connected to an antenna by feeder cables. Base station is intended for operation at a fixed location and powered directly or indirectly (e.g., via an AC/DC converter or power supply) by AC mains network, or an extended local DC mains network.

3.1.4 BS type 1-C [3GPP TS 38.113]: New radio base station operating at FR1 with requirements set consisting only of conducted requirements defined at individual antenna connectors.

3.1.5 BS type 1-H [3GPP TS 38.113]: New radio base station operating at FR1 with a requirement set consisting of conducted requirements defined at individual transceiver array boundary connectors and over the air requirements defined at the radiated interface boundary.

3.1.6 BS type 1-O [3GPP TS 38.113]: New radio base station operating at FR1 with a requirement set consisting only of over the air requirements defined at the radiated interface boundary.

3.1.7 BS type 2-O [3GPP TS 38.113]: New radio base station operating at FR2 with a requirement set consisting only of over the air requirements defined at the radiated interface boundary.

3.1.8 continuous phenomena [IEC 60050-161]: Electromagnetic disturbance, the effects of which on a particular device or equipment cannot be resolved into a succession of distinct effects.

3.1.9 electromagnetic disturbance [IEC 60050-161]: Any electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter.

3.1.10 electromagnetic emission [IEC 60050-161]: The phenomenon by which electromagnetic energy emanates from a source.

3.1.11 electromagnetic interference (EMI) [IEC 60050-161]: Degradation of the performance of an equipment, transmission channel or system caused by an electromagnetic disturbance.

3.1.12 enclosure port [IEC CISPR 32]: Physical boundary of the equipment under test through which electromagnetic fields may radiate.

3.1.13 Equipment under test [EC CISPR 16-2-3]: Equipment (devices, appliances and systems) subjected to electromagnetic compatibility emission compliance (conformity assessment) tests.

3.1.14 immunity (to a disturbance) [IEC 60050-161]: The ability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance.

3.1.15 integral antenna [ITU-T K.114]: Antenna which may not be removed during the tests, according to the manufacturer's statement.

3.1.16 necessary bandwidth [ITU-R SM.329-12]: For a given class of emission, the width of the frequency band which is just sufficient to ensure the transmission of information at the rate and with the quality required under specified conditions.

3.1.17 out-of-band emission [ITU-R SM.329-12]: Emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions.

3.1.18 port [ITU-T K.114]: Particular interface of the specified equipment with the external electromagnetic environment (Figure 1).

NOTE – An interface, which uses optical fibre, is not a port for the purposes of testing because it does not interact with the electromagnetic environment within the frequency range. An optical fibre interface may still be used in the assessment of performance.

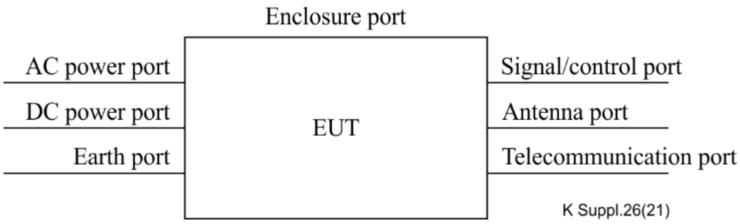

Figure 1 – Port

3.1.19 spurious emission [ITU-R SM.329-12]: Emission on a frequency or frequencies which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions.

3.1.20 transient phenomena [IEC 60050-161]: Pertaining to or designating a phenomenon or a quantity which varies between two consecutive steady states during a time interval that is short compared with the time-scale of interest.

3.1.21 throughput [ITU-T K.114]: The number of payload bits successfully received per second for a reference measurement channel in a specified reference condition.

3.1.22 wired network port [IEC CISPR 32]: Point of connection for voice, data and signalling transfers intended to interconnect widely-dispersed systems by direct connection to a single-user or multi-user communication network (for example CATV, PSTN, ISDN, xDSL, LAN and similar networks).

NOTE – These ports may support screened or unscreened cables and may also carry AC or DC power where this is an integral part of the telecommunication specification.

3.1.23 unwanted emissions [ITU-R SM.329-12]: Consist of spurious emissions and out-of-band emissions.

3.2 Terms defined in this Supplement

This Supplement defines the following terms:

3.2.1 channel bandwidth: The RF bandwidth supporting a single new radio (NR) radiofrequency (RF) carrier with the transmission bandwidth configured in the uplink or downlink of a cell. The channel bandwidth is measured in MHz and is used as a reference for transmitter and receiver RF requirements.

3.2.2 exclusion band: Frequency range(s) not subject to test or assessment.

3.2.3 lower RF bandwidth edge: The frequency of the lower edge of the base station RF bandwidth, used as a frequency reference point for transmitter and receiver requirements.

3.2.4 operating band: Frequency range in which NR operates (paired or unpaired) that is defined with a specific set of technical requirements.

3.2.5 receiver exclusion band: Band of frequencies over which no tests of radiated immunity of a receiver are made, and expressed relative to the base station receive band.

3.2.6 signal port: Port intended for the interconnection of components of equipment under test (EUT), or between EUT and associated equipment and used in accordance with relevant functional specifications (for example, for the maximum length of cable connected to it).

3.2.7 spatial exclusion zone: Range of angles where no tests of radiated immunity are made for BS type 1-O or BS type 2-O (i.e., half sphere around the radiating direction of the EUT).

3.2.8 transceiver unit: Active unit consisting of transmitter and/or receiver which transmits and/or receives radio signals, and which may include passive RF filters.

3.2.9 transmitter exclusion band: Band of frequencies over which no tests of radiated immunity of a transmitter are made and which is expressed relative to the carrier frequencies used (the carrier frequencies of the base station activated transmitter(s)).

3.2.10 upper RF bandwidth edge: The frequency of the upper edge of the base station RF bandwidth, used as a frequency reference point for transmitter and receiver requirements.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

AA Antenna Array

AAS Active Antenna System

AC Alternating Current

BS Base Station

DC Direct Current

EMC Electromagnetic Compatibility

EMF Electromagnetic Field

ESD Electrostatic Discharge

EUT Equipment Under Test

EVM Error Vector Magnitude

NR New Radio

OTA Over The Air

PCB Printed Circuit Board

RDN Radio Distribution Network

RF Radio Frequency

RIB Radiated Interface Boundary

RXU Receiver Units

SDL Supplementary Downlink

SUL Supplementary Uplink

TAB	Transceiver Array Boundary
TRXU	Transceiver Unit
TRXUA	Transceiver Unit Array
TXU	Transmitter Units
UE	User Equipment
Δf_{OBUE}	Maximum offset of the operating band unwanted emissions mask from the downlink operating band edge
Δf_{OOB}	Maximum offset of the out-of-band boundary from the uplink operating band edge
$F_{DL,low}$	The lowest frequency of the downlink operating band
$F_{DL,high}$	The highest frequency of the downlink operating band
$F_{UL,low}$	The lowest frequency of the uplink operating band
$F_{UL,high}$	The highest frequency of the uplink operating band
$\Delta f_{RIexclusion}$	Maximum offset of the radiated immunity exclusion band from the uplink operating band edge for test without spatial exclusion zone applied

5 Conventions

None.

6 5G NR base station new types

Some background information is given in this clause. The [3GPP TS 38.113] was presented to the public in its first version, v15.0.0, in December 2017 and its most recent version is v15.6.0.

Two frequency ranges are defined in the 3GPP base station (BS) radio specification [3GPP TS 38.104] shown below in Table 1:

Table 1 – Frequency range

	Frequency range
FR1	410 MHz-7 125 MHz
FR2	24 250 MHz-52 600 MHz

At the same time, 4 different corresponding BS types are defined:

- BS type 1-C
- BS type 1-H
- BS type 1-O
- BS type 2-O

To these different BS types, a different applicability of the EMC tests is defined. In particular, the BS type 1-C is still a non-AAS BS while the other three types (i.e., BS type 1-H, 1-O and 2-O) are all BSs with AAS.

7 5G AAS Implementation in base stations

7.1 BS type 1-C

The BS type 1-C transmitter and receiver interface are shown below in Figures 2 and 3. The RF requirements are applied at the BS antenna connector (port A) for a single transmitter or receiver with a full complement of transceivers for the configuration in normal operating conditions. If any external apparatus such as an amplifier, filter or a combination of such devices is used, requirements apply at the far end antenna connector (port B).

BS type 1-C has the same RF architecture as a E-UTRA BS. The antennas are connected to port A or port B with co-axial cable and the largest number of antennas is 8.

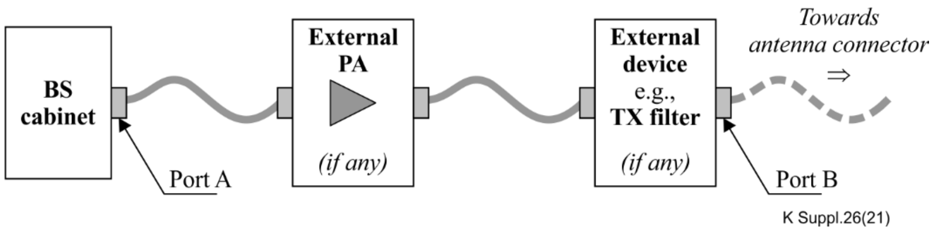

Figure 2 – BS type 1-C Transmitter interface

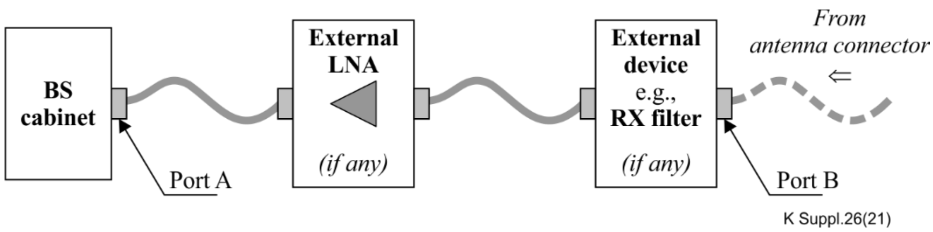

Figure 3 – BS type 1-C Receiver interface

7.2 BS type 1-H

In BS type 1-H the radio architecture is represented by three main functional blocks: the transceiver unit array (TRXUA), the radio distribution network (RDN), and the antenna array (AA). The transceiver units (TRXU) interface with the base band processing within the AAS BS.

The TRXUA consists of multiple transmitter units (TXUs) and receiver units (RXUs). The TXU takes the baseband input from the AAS BS and provides the RF TX outputs. The RF TX outputs are distributed to the AA via an RDN. The RXU performs the reverse of the TXU operations. The RDN performs the distribution of the TX outputs into the corresponding antenna paths and antenna elements, and a distribution of RX inputs from antenna paths in the reverse direction. The TXU and RXU can be separated and can have different mapping through the RDN towards the AA.

The transceiver array boundary (TAB) is the point or points at which the TRXUA is connected to the RDN. The point where a TXU or RXU connects with the RDN is called the TAB connector. The TAB connector is defined as a conducted requirement reference point. The transmitted signal per carrier from one TXU appears at one or more TAB connector(s) and the received signals per carrier from one or more TAB connector(s) appear at a single RXU.

Figure 4 shows a general BS type 1-H radio architecture, where M is the total number of transceiver units and K is the total number of TAB connectors at the transceiver array boundary.

NOTE 1 – The RDN may consist of a simple one to one mapping between the TXU(s)/RXU(s) and the passive AA. In this case, the RDN would be a logical entity but not necessarily a physical entity.

NOTE 2 – The AA includes various implementations and configurations e.g., polarization, array geometry (including element factor and element separation).

NOTE 3 – The physical location of the TRXUA, the RDN and the AA may differ from this logical representation and is implementation dependent.

NOTE 4 – No specific mapping in the RDN between TAB connectors and antenna elements is assumed. Further, the number of separate receiver and transmitter units as well as the mapping in the RDN between TAB connectors and radiating elements can differ between the transmit and receive directions. The BS type 1-H reference architecture allows for full asymmetry between the receiver path and the transmit path.

NOTE 5 – For BS type 1-H capable of supporting applications employing beamforming, all TAB connectors or subgroups of TAB connectors can be configured with designated amplitude and phase weights such that one or more beams are radiated from the AA.

NOTE 6 – The fixed scaling factor of 8 has been assumed. The scaling function may be further reconsidered for future releases if the maximum number of layers/streams supported in NR is changed.

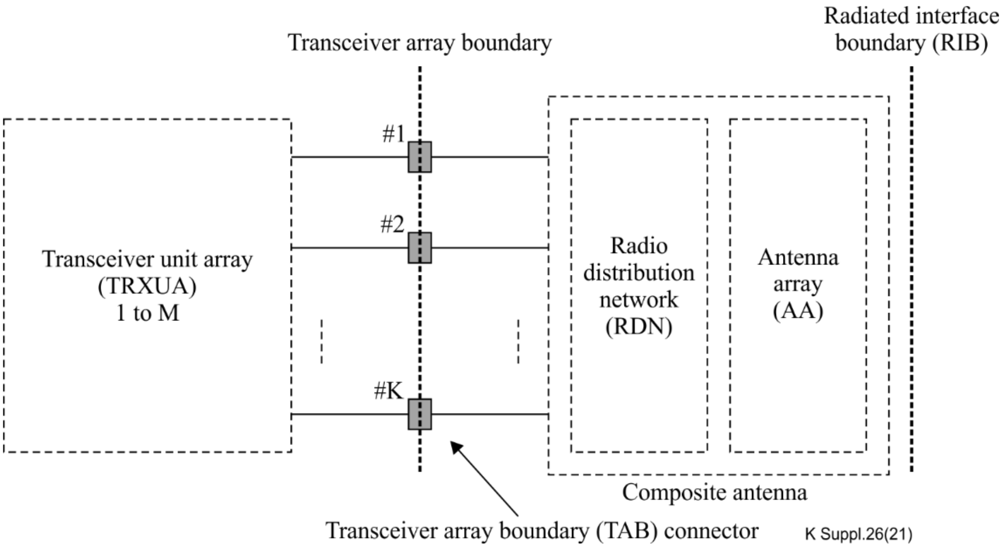

Figure 4 – General architecture of BS type 1-H (M: Total number of transceiver units; K: Total number of TAB connectors at the transceiver array boundary)

7.3 BS type 1-O and BS type 2-O

The OTA BS types have no transceiver array boundary or TAB connectors defined as the antenna is integrated with the BS.

Figure 5 shows a general architecture of an OTA BS, where P is the total number of transceiver units and $P \geq 8$.

NOTE 1 – If a BS type 1-O is declared to support more than 1 cell (N_{cells}>1) the total number of transceiver units must be greater than $8 \times N_{cells}$.

NOTE 2 – The fixed scaling factor of 8 is based on the maximum number of layers/streams specified in release 12 of the 3GPP E-UTRA specifications. The scaling function may be further reconsidered for future releases if the maximum number of layers/streams supported in NR is changed.

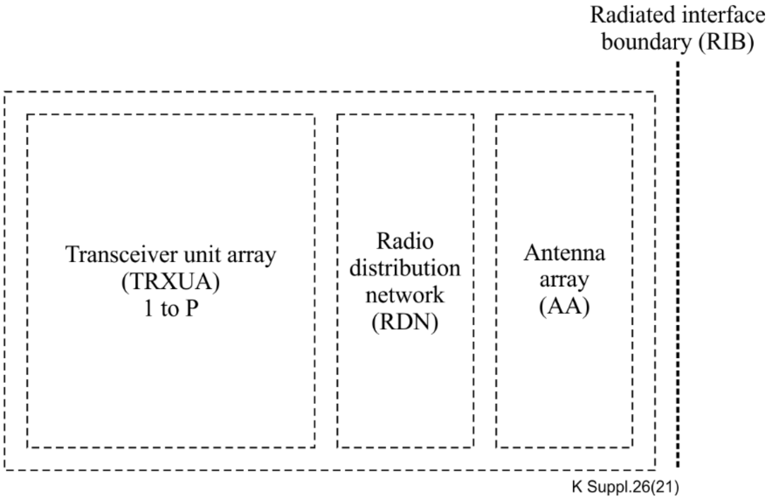

Figure 5 – General architecture of BS type 1-O and BS type 2-O (P – total number of transceiver units, ≥ 8)

8 Impact on EMC test methods with introduction of 5G AAS

8.1 Radiated immunity

8.1.1 General requirements

The general requirements for test methods according to [IEC 61000-4-3] and [ITU-T K.114] shall be applied.

8.1.2 Spatial exclusion zone

In the range of angles, except for the operational range of angles of the BS type 1-O and BS type 2-O antenna (i.e., except for the half sphere around the EUT radiating direction as depicted in Figure 6) and for the frequency range above 690 MHz (according to the test method in [ETSI EN 301 489-50]), the EMC RF electromagnetic field immunity requirement applies.

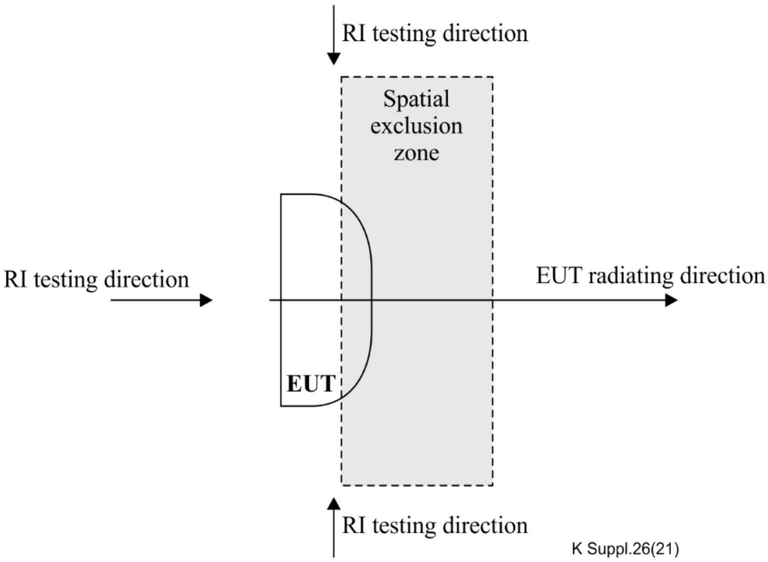

Figure 6 – EMC RF electromagnetic field immunity requirement testing directions for BS type 1-O and BS type 2-O (horizontal plane depicted) with the spatial exclusion zone applied

8.1.3 Transmitter exclusion band

The transmitter exclusion band for 5G BS is the frequency range over which no tests of radiated immunity of a transmitter are made. The transmitter exclusion band only applies to BS type 1-O.

The transmitter exclusion band is defined as:

$$F_{\mathrm{DL,low}} - \Delta f_{\mathrm{OBUE}} < f < F_{\mathrm{DL,high}} + \Delta f_{\mathrm{OBUE}}$$

Where:

Values of $F_{\mathrm{DL,low}}$ and $F_{\mathrm{DL,high}}$ are defined for each operating band in subclause 5.2 of [3GPP TS 38.104].

The value of Δf_{OBUE} is derived considering the width of the operating band, and is defined in Table 2 according to [3GPP TS 38.104].

For BS capable of multiband operation, the total transmitter exclusion band is a combination of the exclusion bands for each operating band supported by BS.

NOTE 1 – The transmitter exclusion bands do not apply for SUL bands.

NOTE 2 – As the radiated immunity testing is defined in the frequency range 80 MHz to 6 GHz, there is no transmitter exclusion band defined for BS type 2-O.

8.1.4 Receiver exclusion band

The receiver exclusion band for BS is the frequency range over which no tests of radiated immunity of a receiver are made.

The receiver exclusion band is defined as:

$$F_{\mathrm{UL,low}} - \Delta f_{\mathrm{OOB}} < f < F_{\mathrm{UL,high}} + \Delta f_{\mathrm{OOB}}$$

Where:

Values of $F_{\mathrm{UL,low}}$ and $F_{\mathrm{UL,high}}$ are defined for each operating band in subclause 5.2 of [3GPP TS 38.104].

The value of Δf_{OOB} is derived considering the width of the operating band, and is defined in Table 2 according to [3GPP TS 38.104].

Table 2 – Δf_{OOB} offset for NR operating bands

BS type	Operating band characteristics	Δf_{OOB} (MHz)
BS type 1-C	$F_{\mathrm{UL,high}} - F_{\mathrm{UL,low}} \leq 200$ MHz	20
	200 MHz $< F_{\mathrm{UL,high}} - F_{\mathrm{UL,low}} \leq 900$ MHz	60
BS type 1-H, BS type 1-O	$F_{\mathrm{UL,high}} - F_{\mathrm{UL,low}} < 100$ MHz	20
	100 MHz $\leq F_{\mathrm{UL,high}} - F_{\mathrm{UL,low}} \leq 900$ MHz	60

In case the spatial exclusion zone (as depicted in Figure 6) is not used during the EMC RI testing, the receiver exclusion band for BS type 1-O is defined as:

$$F_{\mathrm{UL,low}} - \Delta f_{\mathrm{RIexclusion}} < f < F_{\mathrm{UL,high}} + \Delta f_{\mathrm{RIexclusion}}$$

Where the values of $\Delta f_{\mathrm{RIexclusion}}$ are defined in Table 3.

Table 3 – Maximum $\Delta f_{\mathrm{RIexclusion}}$ offset outside the uplink operating band

Operating band characteristics	$\Delta f_{\mathrm{RIexclusion}}$ (MHz)
100 MHz $\geq F_{\mathrm{UL,high}} - F_{\mathrm{UL,low}}$	60
100 MHz $< F_{\mathrm{UL,high}} - \mathrm{F}_{\mathrm{UL,low}}$	200

For BSs capable of multiband operation, the total receiver exclusion band is a combination of the exclusion bands for each operating band supported by the BS.

NOTE 1 – The receiver exclusion bands do not apply for supplementary downlink (SDL) bands.

NOTE 2 – As radiated immunity testing is defined in the frequency range 80 MHz to 6 GHz, there is no receiver exclusion band defined for BS type 2-O.

8.2 Consideration of EMF protection during EMC test

The antenna of BS type 1-O and BS type 2-O are integrated on the printed circuit board (PCB). During the EMC test, in order to establish the communication link between the BS and the user equipment (UE) simulator, the BS still needs to transmit; typical full power transmit is defined in [ITU-T K.114], [ETSI EN 301 489-1] and [ETSI EN 301 489-50]. If this is still the case for BS type 1-O and BS type 2-O, the radiated power coming out from the BS antenna will be significantly larger than the EMF exposure limit, which is defined in the ICNIRP[1] standards. The ICNIRP requirement is listed in Table 4.

Table 4 – ICNIRP EMF exposure requirement

Power density (W/m^2)		
10-400 (MHz)	400-2 000 (MHz)	2 000-10 000 (MHz)
28	$1.375f^{1/2}$	61

For test operator safety, different methods can prevent high EMF exposure.

For the conducted emission test, which needs the BS to transmit in full power, a shielding room or anechoic chamber is proposed as in Figure 7 below. The test operator will perform the EMC test outside the shielding room or anechoic chamber.

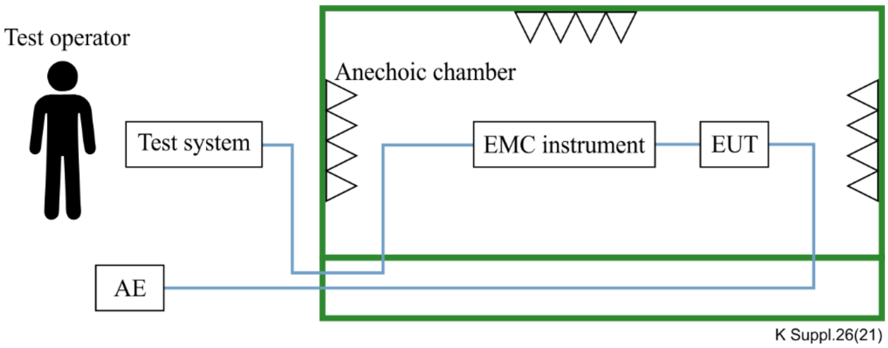

Figure 7 – Test method for conducted emission (AE: Auxiliary equipment)

Other EMC tests, such as the surge, EFT, conducted immunity and ESD tests, can be performed with reduced RF transmit power of the BS. During those EMC tests, the RF output power may be reduced to a power level sufficient for establishing and maintaining the required communication link.

9 Performance assessment of 5G AAS

Clause 5 of [ETSI EN 301 489-50] and clause 9 of [ITU-T K.114] shall apply for the assessment of throughput in downlink and uplink for 5G AAS BS.

[1] International Commission on Non-ionizing Radiation Protection, https://www.icnirp.org

The monitoring of the throughput in downlink requires the support of the core network equipment. The core networking equipment is very complex. Currently, in the EMC test for the BS, the throughput in downlink is generally not monitored.

There is a certain relationship between EVM and the throughput for the transmitter. While the throughput in downlink cannot be monitored, EVM can be used as an alternative monitoring method in downlink.

10 Performance criteria of 5G AAS

Clause 6 of [3GPP TS 38.113] shall apply for the performance criteria of the throughput in downlink and uplink.

The assessment of the downlink performance of the BS can also be replaced by the EVM value output by the transmitter. It is required that the EVM value of the transmitter in the highest-order modulation mode shall not be higher than that specified in Table 5.

Table 5 –EVM requirements for 5G AAS BS downlink performance criteria for continuous phenomena

Modulation scheme for PDSCH	Required EVM	5G NR BS Type
QPSK	18.5%	1-C,1-H,1-O,2-O
16QAM	13.5%	1-C,1-H,1-O,2-O
64QAM	9%	1-C,1-H,1-O,2-O
256QAM	4.5%	1-C,1-H,1-O
NOTE – EVM requirements for *BS type 1-C* and *BS type 1-H* are defined in subclause 6.5.3.5 of [3GPP TS 38.141-1] and subclause 6.6.3.5 of [3GPP TS 38.141-2].		

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Printed in Switzerland
Geneva, 2021