Assessment of the exposure of the general public to 5G electromagnetic waves

Part 2: first measurement results on 5G pilots in the 3,400-3,800 MHz band

April 2020

Executive summary

This report is part of a general study on the assessment of exposure of the general public to electromagnetic waves from 5G networks. The first part was a general presentation of 5G from an exposure point of view. This second part covers several representative pilot deployments carried out in France to test the deployment of 5G steered beam antennas in the 3400-3800 MHz band.

Exposure measurements using the applicable ANFR measurement protocol are taken before and after powering up the sites representing various operator, manufacturer and antenna type configurations. The post-initialisation measurements were taken without traffic as these sites were not open to subscribers at the time. In the absence of traffic, the signalling signals are observed which makes it possible for the base station to scan the coverage area for possible users. Forty-three sites were measured, which showed that before the 5G sites were powered up there was no emission in this frequency band, and that after they were powered up, in the absence of traffic, the average exposure level in the 5G band was 0.06 V/m, with a maximum level of 0.36 V/m. These levels are well below the regulatory limit value of 61 V/m in this frequency band.

Additional measurements were also taken at a limited number of sites in specific test configurations, in particular with continuous data traffic in a beam locked in a given direction and when downloading a 1 GB file. The following table summarises the main electric field strengths measured:

Town/City	Manufacturer	Operator	Electric field strength without traffic	Maximum electric field strength when the antenna is transmitting continuously at full load in a given direction	Electric field strength received when sending a 1 GB file in a given direction
Mérignac	Huawei	Bouygues Telecom	0.1-0.2 V/m	9 V/m	1.1 V/m
Châtillon	Huawei	Orange	0.01-0.2 V/m	0.65 V/m	--
Toulouse	Huawei	SFR	0.1-0.2 V/m	8.3 V/m	0.8 V/m
Douai	Ericsson	Orange	0.1 V/m	1.4 V/m	--
Nozay	Nokia	Nokia	0.05-0.6 V/m	6 V/m	1.6 V/m
Pau	Huawei	Orange	0.01-0.1 V/m	1.8 V/m	--

These measurements were used to observe the frequency spectrum and temporal occupancy of the 5G signals. They also highlighted the variation in the level of exposure depending on use and led to the proposal of a new indicator to better reflect the actual exposure created by 5G networks with steerable beams. This indicator is based on a predictable 5G usage pattern, which translates into one gigabyte of data being sent in a given direction every 6 minutes. Assuming an average speed of 500 Mbps, the antenna then transmits in the given direction about 15 seconds every 6 minutes (i.e. about 4% of the time). The assumptions to define this indicator will be compared with the exposure measurements from the field for 5G commercial networks. They will be revised if necessary.

This indicator results in a reduction factor that is used to assess the exposure in live conditions based on the theoretical maximum antenna power. The field strengths at 100 metres from a 5G antenna resulting from the application of the indicator appear to be comparable to those found at the same distance from a 4G antenna. However, for 4G, the reduction factor applies to the maximum antenna gain value. As this is only found in the main antenna direction, outside this main direction the field strength will be lower. On the other hand, with the 5G steered beam antennas, the exposure calculated using the indicator will be valid in a higher number of directions.

These initial measurements made it possible to cover several antenna configurations and different 5G implementations in well-controlled conditions linked to the pilot deployments. After the networks open to the public, new measurements will make it possible to test more realistic configurations in terms of traffic.

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1. Introduction

This report is part of a general study on the assessment of exposure of the general public to electromagnetic waves from 5G networks. The first part was a general presentation of 5G from an exposure point of view. This second part covers several representative pilot deployments carried out in France to test the deployment of 5G antennas in the 3,400 - 3,800 MHz band in live conditions.

The first 3,400 - 3,800 MHz band considered for 5G deployment is a good compromise between coverage and capacity. Long-range "macro" type cells will be able to be implemented in this frequency band to guarantee good coverage, while having the extended bandwidths required for very high speed mobile. In order to achieve the objectives of 5G, higher instant transmitted powers are required and 5G will rely on massive MIMO *(Multiple Input Multiple Output)* technology which allows the formation of steered and thinner beams directed towards users *(beamforming)*. As a result, and contrary to previous technologies, the exposure to the waves created by mobile phone relay stations is likely to vary depending on the location of the users who are communicating and on their uses. 5G therefore requires to adjust the exposure assessment procedures.

The objective of the experimental approach is therefore to characterise the exposure created by 5G antenna array access points.

2. Pilot areas in France

At the beginning of 2018, the Arcep opened a "5G pilots" service to issue authorisations to use frequencies in the frequency bands being considered for 5G, on a transitional basis and within the limits of their availability. The Arcep maintains a dashboard of these pilot areas: https://www.arcep.fr/cartes-et-donnees/nos-publications-chiffrees/experimentations-5g-en-france/tableau-deploiements-5g.html

Once the authorisation to use the frequencies is obtained from the Arcep, operators must apply to the ANFR for an authorisation to transmit. The ANFR publishes a monthly observatory of mobile network deployments and keeps a record of the 5G supports[1] authorised for these pilots (see Figure 1). However, the permission to transmit issued by the ANFR for an experimental 5G station does not prejudge the actual operational status[2] of that station.

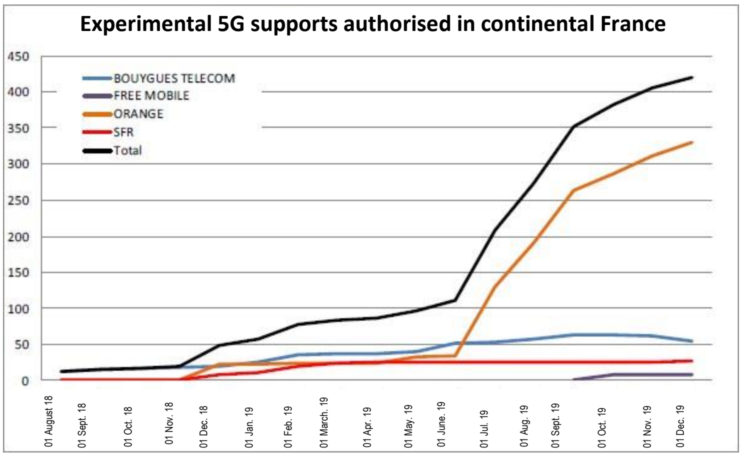


Figure 1: excerpt from the ANFR observatory of mobile network deployments of December 2019.

Table 1 and Figure 2 summarise the main pilots studied in this analysis. This table is not intended to be complete, but presents the first large-scale pilots initially planned by three of the four French mobile operators. Since then, the operators have launched other experimental deployments of 5G antennas in other towns/cities.

Town/City	Operator	Manufacturer
Lille	Orange	Ericsson
Douai	Orange	Ericsson
Châtillon	Orange	Huawei
Nantes	SFR	Huawei
Bordeaux	Bouygues Telecom	Huawei
Pau	Orange	Huawei
Toulouse	SFR	Huawei
Marseilles	Orange	Nokia
Lyon	Bouygues Telecom	Ericsson
Saint-Ouen	Orange	Samsung

Table 1: List of towns/cities, operators and manufacturers concerned by the first pilot 5G deployments in the 3400 MHz - 3800 MHz band.

[1] A support is an infrastructure supporting one or more antennas.
[2] Because of the experimental status of these deployments, the operation of these stations is often interrupted as they are not subject to continuity of service requirements.

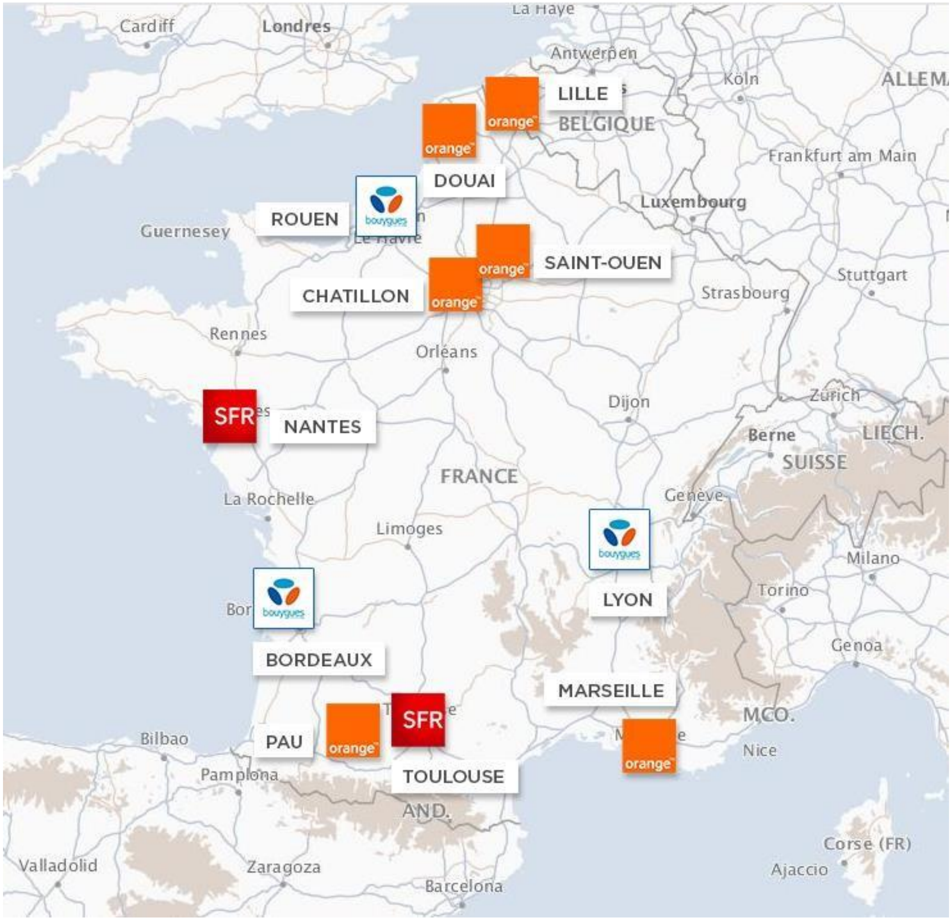


Figure 2: Cities hosting 5G pilot deployments in the 3,400 MHz - 3,800 MHz band that were monitored by the ANFR.

3. COFRAC measurements on pilots

3.1. Presentation

Exposure measurements using the applicable ANFR measurement protocol were taken before and after the powering up of a number of radio sites representing various operator, manufacturer and antenna type configurations.

The cities concerned were Pau, Marseilles, Lille, Douai, Bordeaux, Lyon, Nantes, Rouen, Saint-Ouen and Toulouse, where the Orange, Bouygues Telecom and SFR operators are carrying out the first pilot deployments in the 3.4 GHz - 3.8 GHz band.

The post power-up measurements were taken without traffic as these sites were not open to subscribers at the time. In the absence of traffic, the radio base station emits a signal which makes it possible to set up (or maintain, for a cell change) the connections of users present in its coverage area to the network.

A detailed "case B" measurement of the ANFR measurement protocol was initially taken site by site prior to the powering-up of 5G, in direct view between 100 and 200 m and in the median azimuth sector for each installation. These measurements provided benchmarks.

Subsequent measurements will be taken in the presence of established traffic to study the effect of 5G on overall exposure.

3.2. Results

Forty-three sites were measured.

Before the 5G antennas were powered on, no emissions in this band were detected: levels were measured at less than 0.01 V/m (see Table 2), a value well below 0.05 V/m, the level used in the ANFR protocol to define a significant emission.

After powering on the 5G antennas but in the absence of traffic, the average exposure level created by 5G in the 3.4 - 3.8 GHz band appeared to be very low: it was measured on average at 0.06 V/m, and at the most at 0.36 V/m (see Table 2).

These levels are well below the regulatory limit value of 61 V/m in this frequency band.

	Without 5G	**With 5G signalling**
Average	< 0.01 V/m	0.06 V/m
Maximum	< 0.01 V/m	0.36 V/m

Table 2: Summary of measured electric field strengths in the 3.4 - 3.8 GHz band at 43 sites before and after 5G power up.

4. Supplementary measurements

4.1. Presentation

Supplementary exploratory measurements were organised in a concerted manner between the ANFR, the operators and the manufacturers to test different 5G deployment configurations.

These exploratory tests made it possible to:

- better understand the 5G signals;
- adjust the ANFR measurement protocol to better take into account 5G;
- define an exposure indicator.

At the time of the tests, the 5G pilots were not open to operator subscribers. There were no (or very few) 5G-compatible terminals on the French market. Even so, the assessment of exposure in different configurations required the creation of traffic. Traffic was generated by the following means (see Figure 3):

- the use of a base station test mode, which made it possible to test different network load configurations and numbers of beams;
- mobile receiver test equipment (CPE for *Customer Premises Equipment*);
- a 5G modem receiver controlled by a computer;
- a 5G mobile in receiver mode.

Figure 3: Different equipment used as receivers on 5G pilots. From left to right, a CPE "customer premises equipment", a 5G modem and two 5G mobiles.

During these pilot phases, most of the sites were installed and powered on, but without all possible 5G features having been implemented on them.

4.2. Site characteristics

The sites selected for these supplementary measurements were chosen in order to cover all manufacturers of antennas of which the use is being considered in France, and all the operators carrying out 5G pilots during the period in question. These sites were also selected on the basis of the direct and unobstructed visibility of the sites and a certain number of logistical constraints (access for technical vehicles, presence of a power supply, etc.).

The sites that were the subject of this supplementary analysis are listed in Table 3:

Town/City	Manufacturer	Operator	Antenna type[3]
Mérignac	Huawei	Bouygues Telecom	64T64R
Châtillon	Huawei	Orange	64T64R
Toulouse	Huawei	SFR	64T64R
Douai	Ericsson	Orange	64T64R
Nozay	Nokia	Nokia	64T64R
Pau	Huawei	Orange	32T32R and 8T8R
Saint-Ouen	Samsung	Orange	32T32R

Table 3: List of 5G sites that were the subject of supplementary analysis

4.3. Measurement configuration

Three types of measurement configuration were tested:

- **Configuration without traffic**
  The base station only sent signalling, no users were connected to the network via the antenna.

- **Test configuration with continuous traffic in a blocked beam**
  In this configuration, the base station sent a constant and continuous stream of data in a given direction. This was achieved either by UDP *(User Datagram Protocol*) transfer or by an FTP transfer. UDP transfers have the advantage of minimising uplinks and maximising downlinks. FTP transfers have the advantage of being more realistic. In this configuration, the beam was therefore locked in a given direction.

- **File transfer configuration in a given direction**
  In this configuration, traffic was generated by on-demand downloads using different size files (150 MB, 500 MB, 1 GB, 10 GB, 100 GB).

The measurements were taken at different points: in direct view of the antenna, within an antenna beam and outside the beams. The measurements were taken 1.5 m above the ground, outdoors.

The field strengths were assessed as average values for a 6 minute period, in compliance with regulations. For the record, 5G uses OFDMA modulation which is characterised by a high PAPR (*peak to average power ratio*) level which measures the instant maximum amplitude of the signal compared to its average level.

[3] The antenna type is indicated by a code that specifies the number of transmitters (T) and receivers (R) installed in each antenna. The higher these values, the more the antenna is directional and the thinner the created beams are. These characteristics are detailed in Part 1: General presentation of 5G (pages 12 and following) https://www.anfr.fr/fileadmin/mediatheque/documents/expace/CND/Rapport-ANFR-presentation-generale- 5G.pdf

4.4. Characteristics of the tested 5G signals

The 5G NR standard defined by 3GPP is very open and provides great flexibility in the choice of the many parameters that characterise the signal.

Similarly to 4G, 5G NR uses OFDMA *(orthogonal frequency division multiple access)* modulation, which is based on a division of the time/frequency matrix into elementary resources. In frequencies, the unit is the size of a sub-carrier in kHz; in time, it is the duration of an OFDM symbol in milliseconds. The OFDM symbols are grouped by 14 to form *slots*.

These elementary resources are then grouped together to form frequency blocks (RB for *resource block*) containing a number of sub-carriers, one-millisecond sub-frames and ten-millisecond frames.

In the tested 3,400 - 3,800 MHz band, a TDD[4] *(Time Division Duplexing*) mode is used. The split between *uplink* and *downlink* transmissions over time uses predefined frame formats.

TDD mode may cause interference between base stations or between users. One way to avoid such interference is to make sure that items of equipment that may interfere with each other transmit and receive at the same time: this is called synchronisation. In particular this involves the use of a common frame.

In the first cases observed in the field, this split was achieved by slot with a "DDDSU" format i.e. 3 successive D slots (reserved for downlink traffic), one S slot (for a switch shared between downlink traffic, a buffer zone without transmission and uplink traffic) and one U slot (reserved for uplink traffic). Using this configuration, the TDD ratio is about 75% in favour of the downlink. However, this first format tested in the field was not the one adopted by Arcep in its decision No. 2019-0862 on the synchronisation of terrestrial networks in the 3.4 - 3.8 GHz band in continental France. Another format compatible with this Arcep decision was therefore also tested on certain pilots: the "DDDDDDDSUU" format which also leads to a TDD ratio of around 75% in favour of downlink.

The 5G NR antenna scans its environment to identify the users to be served using SSBs (*synchronisation signal blocks*) that occupy a bandwidth of 20 RB, i.e. 7.2 MHz in the case of the tested pilots.

Table 4 summarises the main characteristics of the 5G signals tested on the pilots which were the subject of supplementary measurements by the ANFR.

[4] The duplexing modes are defined in Part 1: general presentation of 5G (page 10) https://www.anfr.fr/fileadmin/mediatheque/documents/expace/CND/Rapport-ANFR-presentation-generale-5G.pdf

Parameters	Tested 5G pilots
Bandwidth	100 MHz
Spacing between sub-carriers	30 kHz
Size of an RB resource block	12 sub-carriers
Number of available resource blocks	273
Frame duration	10 ms
Slot duration	0.5 ms
Number of symbols per slot	14 symbols
Frame format	DDDSU or DDDDDDDSUU
TDD Ratio	75% downlink
Signalling signal position (SSB)	central or lower band frequency
SSB frequency	20 ms
Number of SSBs	1, 6, 7 or 8

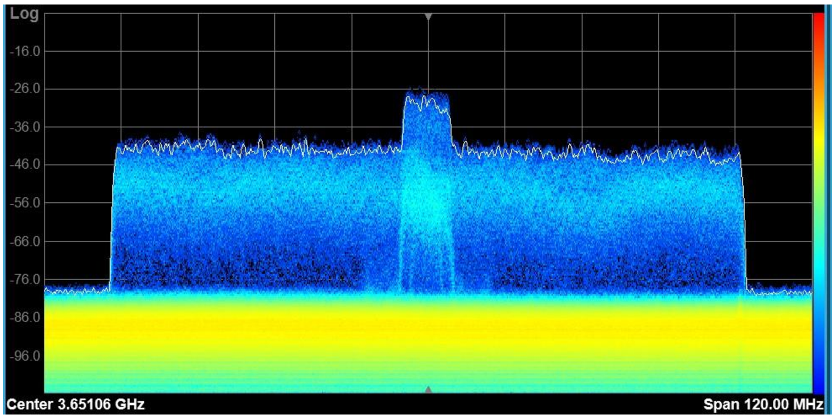
Table 4: General characteristics of the 5G signals tested on the pilots which were the subject of supplementary measurements by the ANFR.

4.5. Results

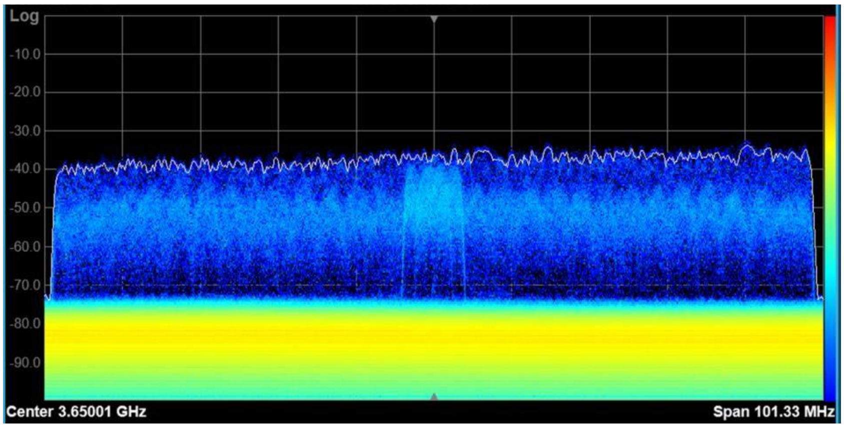
4.5.1. Without traffic

4.5.1.1. Spectral vision

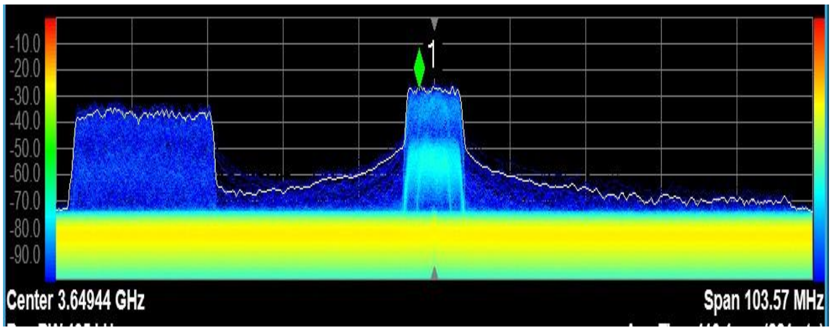
In the absence of traffic, only signalling is transmitted. Figure 4 shows the spectra observed in the absence of traffic for the different manufacturers. The colours indicate the occurrence of power levels, indicated in logarithmic scale on the ordinate, depending on the frequency on the abscissa (100 or 120 MHz around the central frequency of the antenna's transmitting band). The most frequently measured level is shown in yellow and corresponds to the noise level in the band: indeed, in the absence of traffic, most of the time there are no transmissions. More rarely, signalling signals are transmitted (in blue in the figure). These signalling signals are composed of SSBs which occupy a bandwidth of 20 RB i.e. 7.2 MHz, and are located in the centre of the band, except in the case of Samsung where the SSBs are located at the beginning of the band. The other signals, which are spread over the whole spectrum for Huawei or Ericsson or over part of it for Nokia, are other RS *(reference signal*) signals.



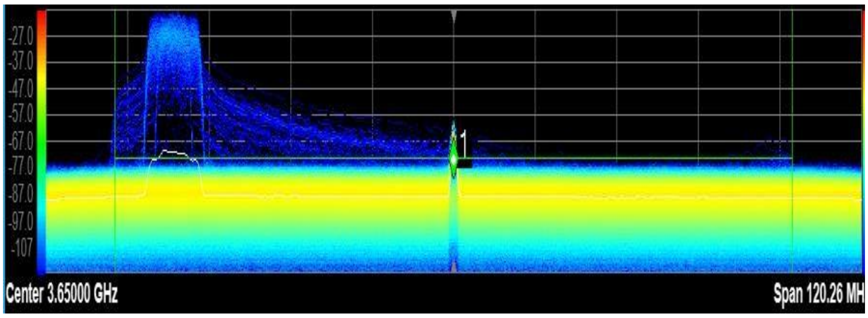
(a) Huawei - Bouygues Telecom - Mérignac



(b) Ericsson - Orange - Douai



(c) Nokia - Nozay

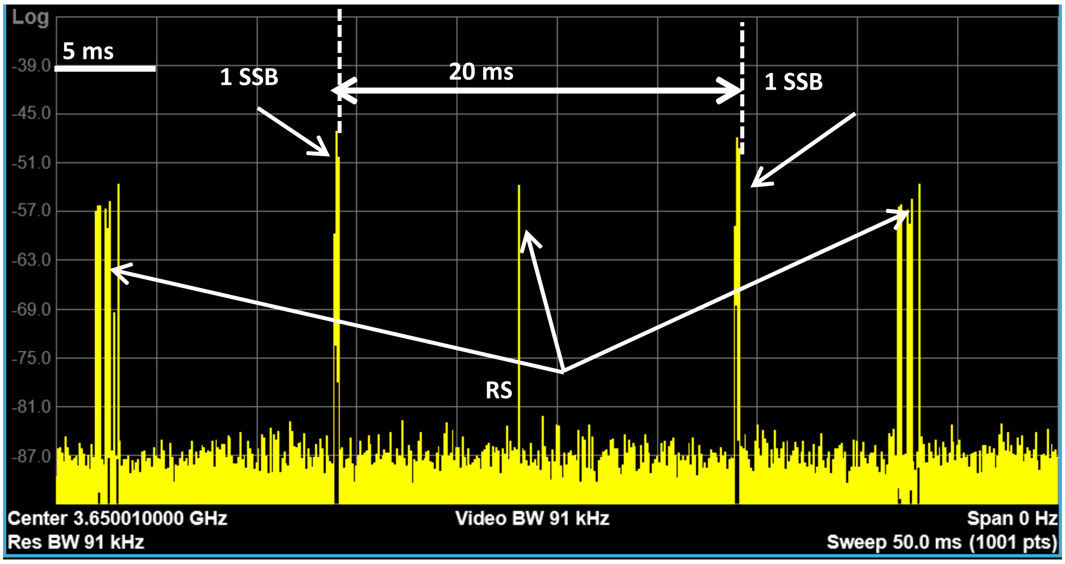


(d) Samsung - Orange - Saint-Ouen

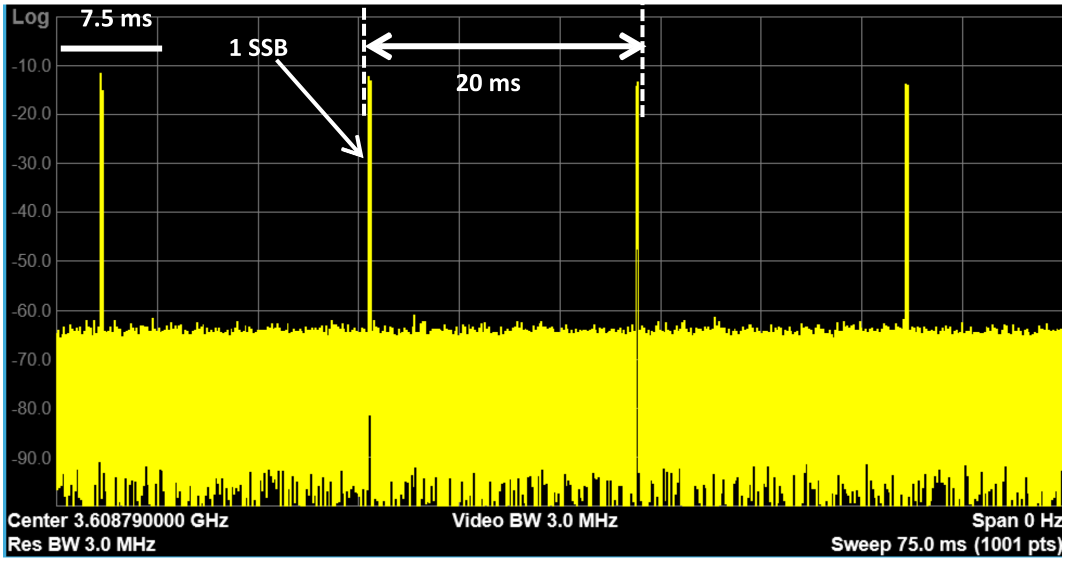
Figure 4: View of the spectrum in the absence of traffic. Y-axis, received power level in logarithmic scale, depending on the frequency on the x-axis (100 or 120 MHz around the central frequency of the antenna's transmitting band), the colours indicate the occurrence of the observed levels, most of the time only the noise level in the band is measured (indicated in yellow) and from time to time the signalling signals, indicated in blue, are observed.

4.5.1.2. Time vision

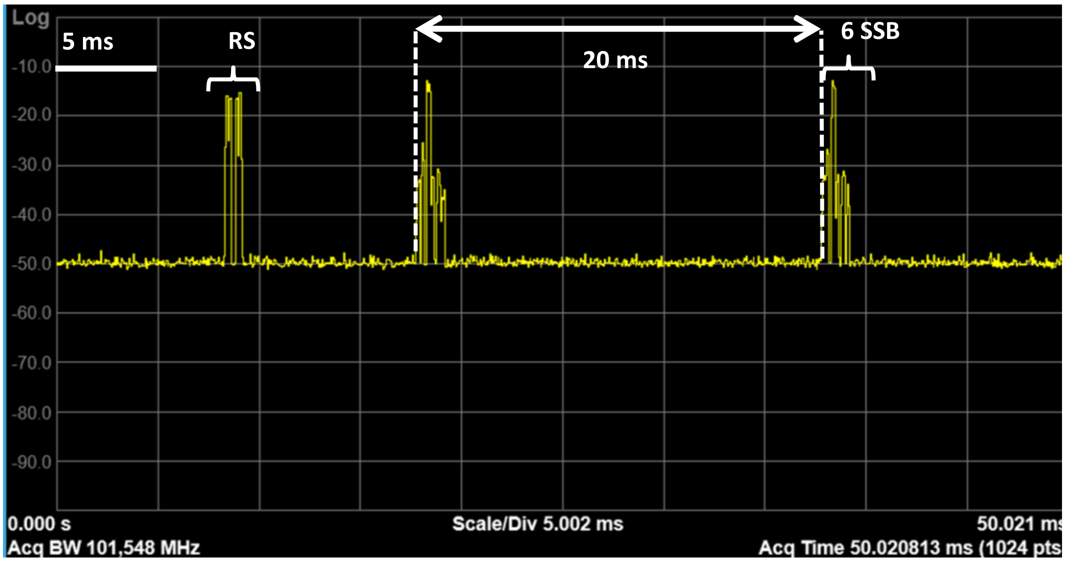
A temporal analysis around the central frequency makes it possible to view the temporal occupancy of the signalling signals. Figure 5 shows the temporal behaviour of the signal over a few frames. 5G frames last 10 ms and SSB signals are transmitted every other frame in the observed configurations. SSB signals range in number from 1 to 8 depending on the case, and sweep the antenna coverage area in less than 2 milliseconds. The other RS reference signals are also visible and very brief.



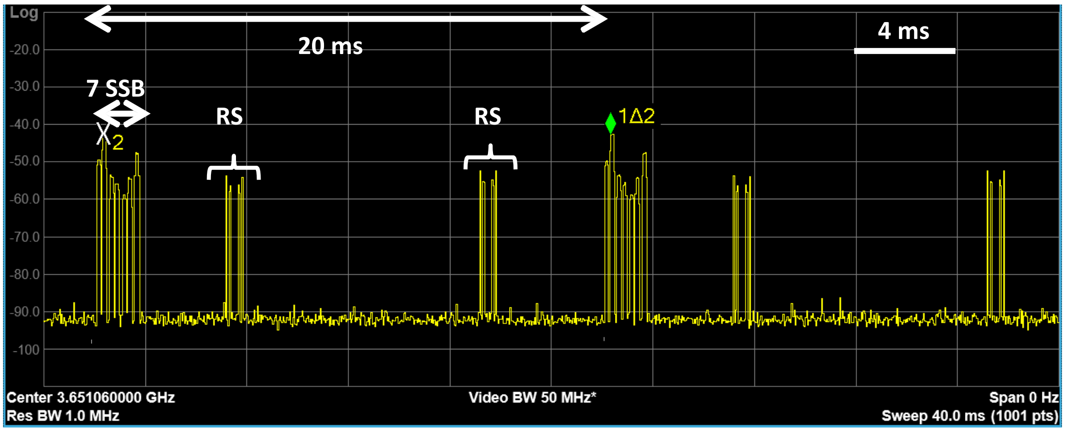
(a) Ericsson - Orange - Douai - 1 SSB



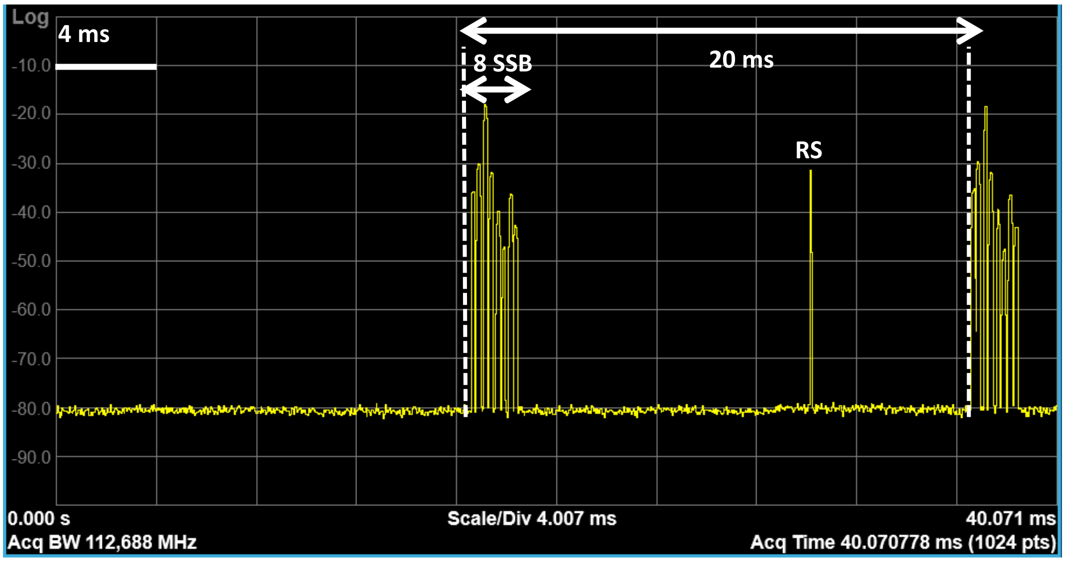
(b) Samsung - Orange - Saint-Ouen - 1 SSB



(c) Nokia - Nozay - 6 SSB



(d) Huawei - Bouygues Telecom - Mérignac - 7 SSB



(e) Nokia - Nozay - 8 SSB

Figure 5: temporal view around the SSB central frequency in the absence of traffic over the duration of a few frames (from 40 ms to 75 ms depending on the site).

4.5.1.3. Levels of received electric fields

The average electric field strength measured at distances ranging from 35 m to 200 m from the 5G antennas, in the absence of traffic, over the 100 MHz transmitter frequency band is between 0.01 V/m and 0.6 V/m (see Table 5).

Town/City	Manufacturer	Operator	Electric field strength without traffic
Mérignac	Huawei	Bouygues Telecom	0.1 V/m - 0.2 V/m
Châtillon	Huawei	Orange	0.05 V/m - 0.2 V/m
Toulouse	Huawei	SFR	0.1 V/m - 0.2 V/m
Douai	Ericsson	Orange	0.1 V/m
Nozay	Nokia	Nokia	0.05 V/m - 0.6 V/m
Pau	Huawei	Orange	0.01 V/m - 0.1 V/m

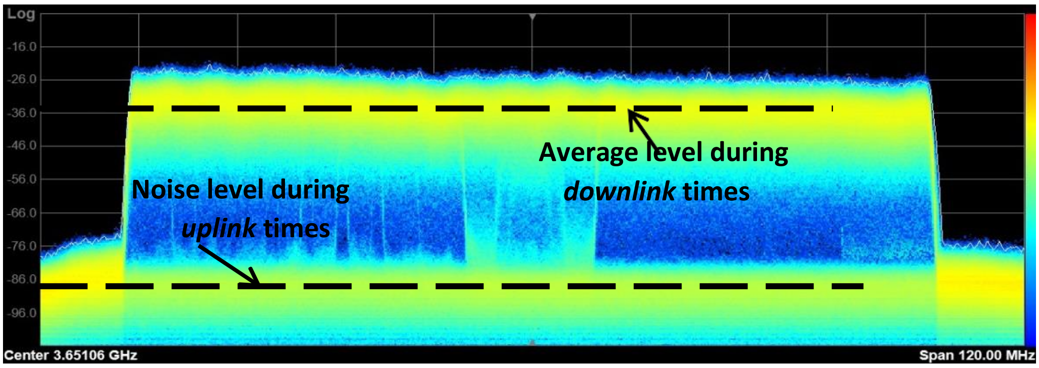
Table 5: Electric field strength measured without traffic on the sites that were the subject of supplementary measurements.

4.5.2. With continuous traffic in one beam

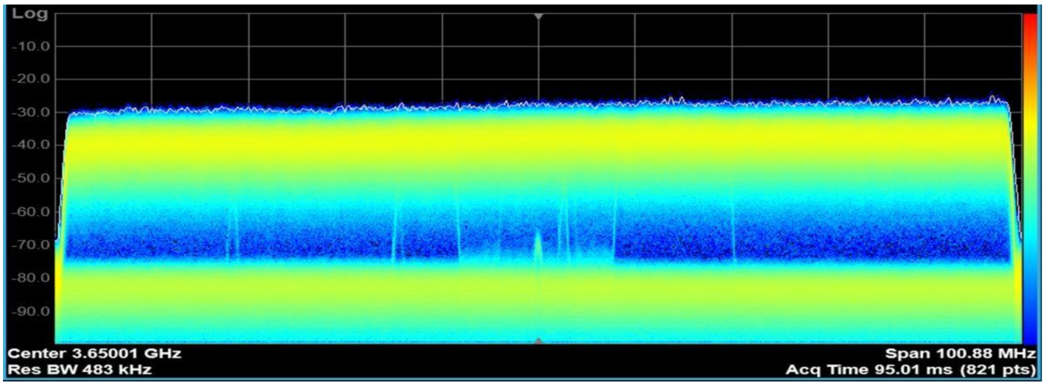
4.5.2.1. Spectral vision

In this test configuration, the base station sends a constant, continuous stream of data in a given direction. Figure 6 illustrates the appearance of spectra over time during a permanent *downlink* transmission. The colours indicate the occurrence of received power levels in logarithmic scale on the ordinate, depending on the frequency on the abscissa (100 or 120 MHz around the central frequency of the antenna's transmitting band). The transmission is permanent, but slots reserved for the *uplink* of the selected TDD format still appear during which no signal is sent by the antenna. The TDD ratio here is 75% and is shown in the spectrum by two frequently measured levels (shown in yellow in the figure), the highest level corresponding to *downlink* transmissions and the lowest level corresponding to the noise level in the band measured on the *uplink* slots during which there is no transmission.

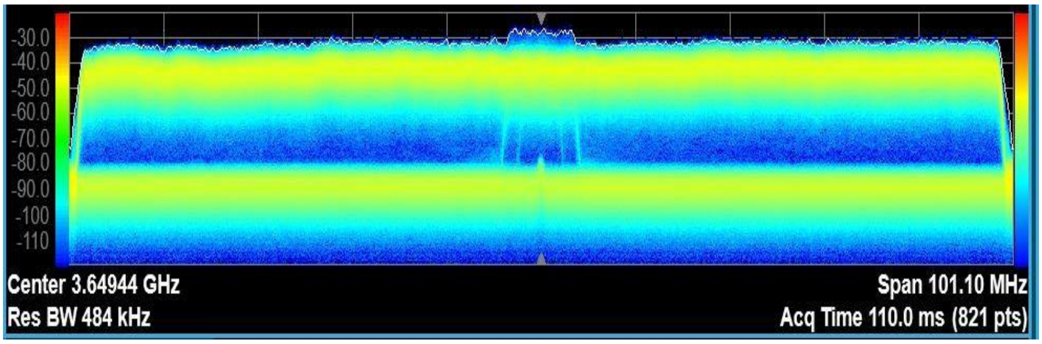
It can be seen that on the Nokia and Samsung sites, the SSB signal levels are above traffic signal levels. A specificity of steered beam antennas is that signalling signals are not necessarily sent with the same radiation pattern as working traffic signals. The gain in the user's direction may therefore be different (stronger or weaker) for SSBs or for traffic, which may result in different levels of reception per elementary resource. On the Nokia and Samsung sites, at the reception point under consideration, SSB reception levels are higher than traffic reception levels. On the Huawei sites in Mérignac and on Ericsson sites at the reception points under consideration, the SSB reception levels are either identical to or weaker than the traffic reception levels, and are therefore not visible on the spectrum.



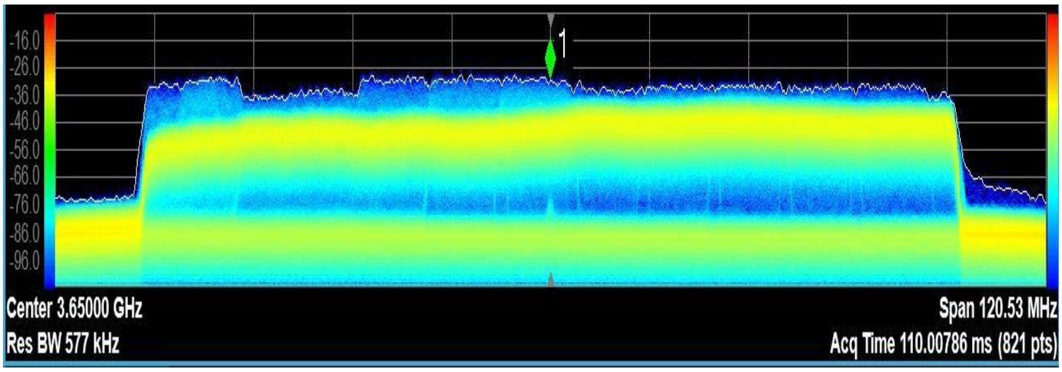
(a) Huawei - Bouygues Telecom - Mérignac - the SSBs are no longer visible due to a level identical to or weaker than the traffic level



(b) Ericsson - Orange - Douai - the SSBs are no longer visible due to an identical or weaker level than the traffic



(c) Nokia - Nozay - the SSBs are visible in the centre of the band due to a slightly stronger level than the traffic

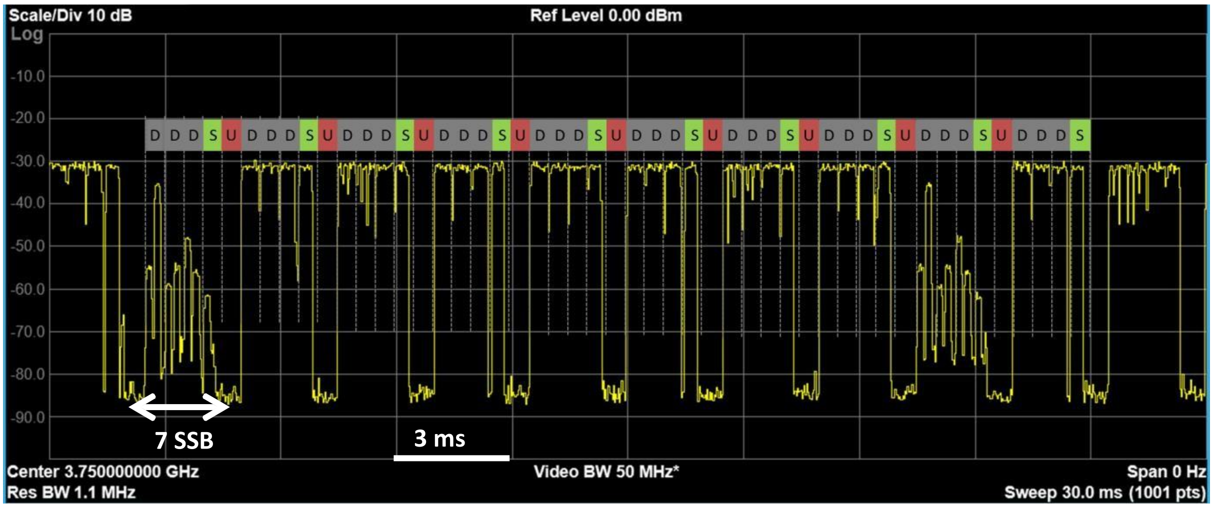


(d) Samsung - Orange - Saint-Ouen - the SSBs are visible at the bottom of the band due to a slightly stronger level than the traffic

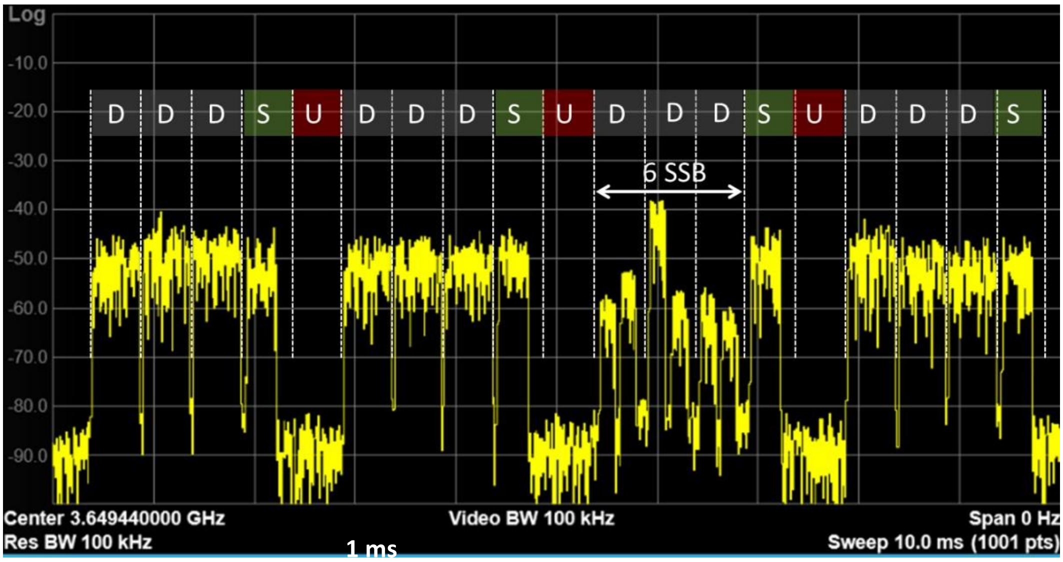
Figure 6: Spectra observed when the antenna transmits all its resources to serve a user in a given direction. On the Y-axis, the received power level in logarithmic scale depending on the frequency on the x-axis (100 or 120 MHz around the central frequency of the antenna's transmitting band). The colours indicate the occurrence of observed levels; yellow levels are the most frequent. All 100 MHz of the band is occupied during downlink transmissions and during uplink times there are no transmissions and the received level is the noise level in the band.

4.5.2.2. Time vision

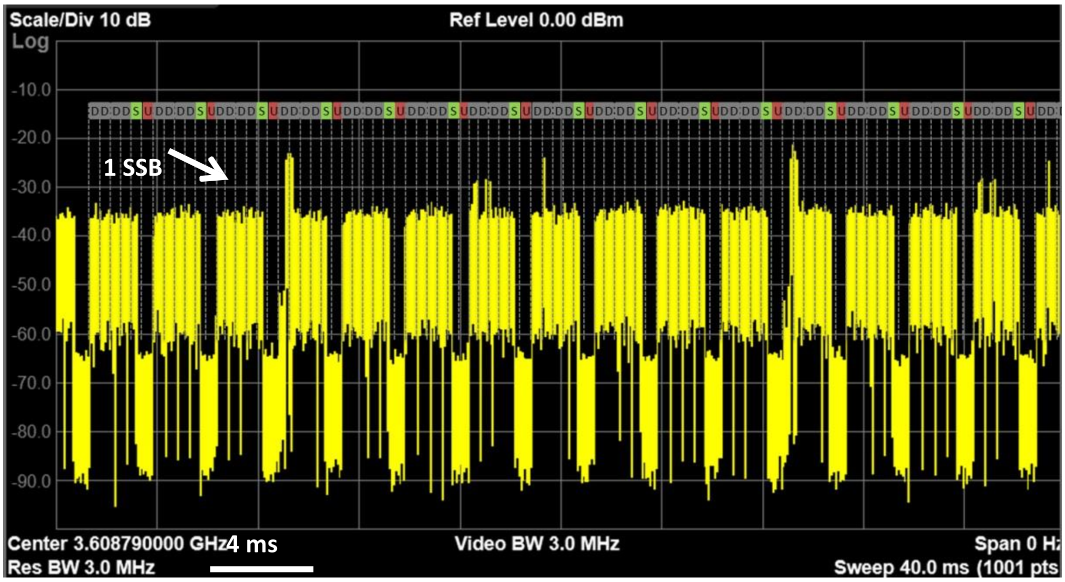
The time vision integrated over a small bandwidth (from 100 kHz to 3 MHz depending on the site) around the SSB central frequency (see Figure 7) makes it possible to observe, for one to a few 10 ms frames, the reception of the SSBs and then the reception of traffic in the defined frame DDDSU or DDDDDDDSUU format depending on the site.



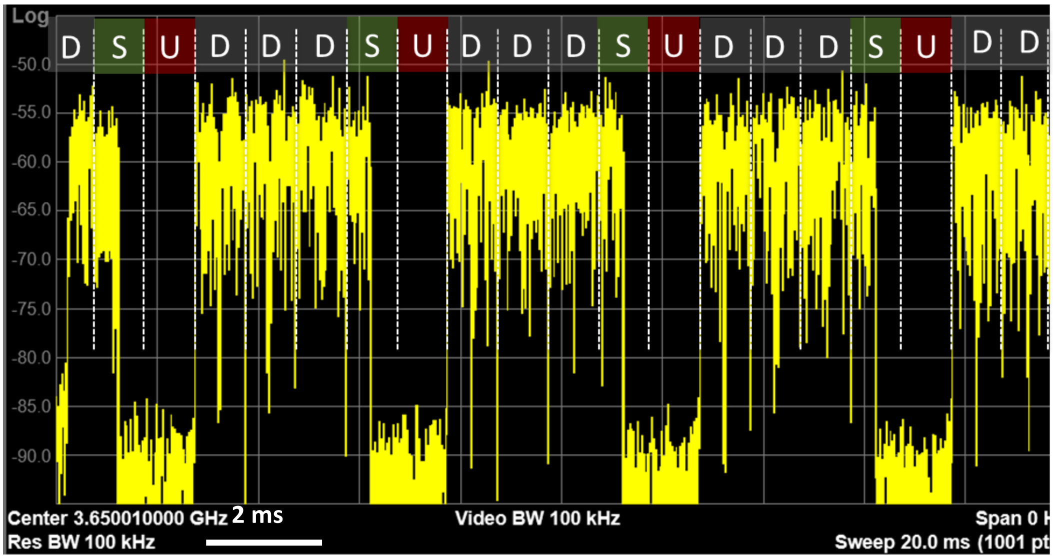
(a) Huawei - SFR - Toulouse - 7 SSB - DDDSU Format



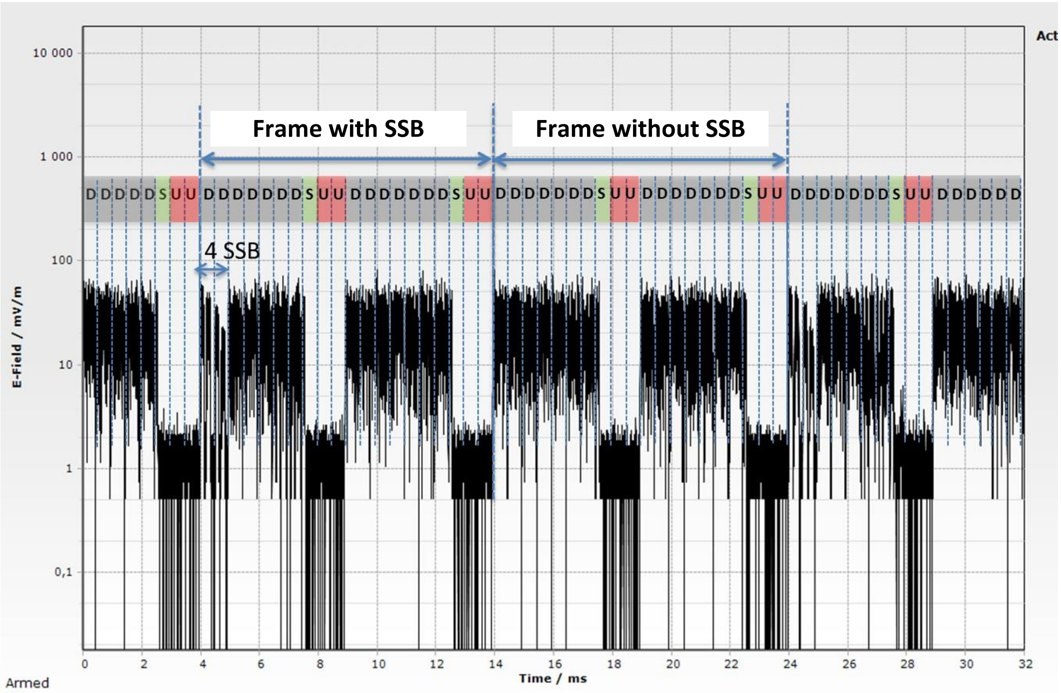
(b) Nokia - Nozay - 6 SSB - DDDSU Format



(c) Samsung - Orange -Saint-Ouen -1 SSB- DDDSU Format



(d) Ericsson - Orange - Douai - 1 undetectable SSB - DDDSU format



(e) Huawei - Orange - Pau -4 SSB - Format DDDDDDDSUU

Figure 7: Time views over a small bandwidth (from 100 kHz to 3 MHz depending on the site) around the SSB central frequency with continuous downlink traffic over a duration of from one to four frames depending on the site.

The SSBs are transmitted over a small part of the frequency band corresponding to 20 RB *(resource blocks*) or, here, 7.4 MHz of band; therefore, outside the SSB transmission frequency band, all the slots are used for traffic, the SSBs are no longer visible, as shown in Figure 8 over 1 MHz at the top of the band (around 3661 MHz) for the DDDSU format.

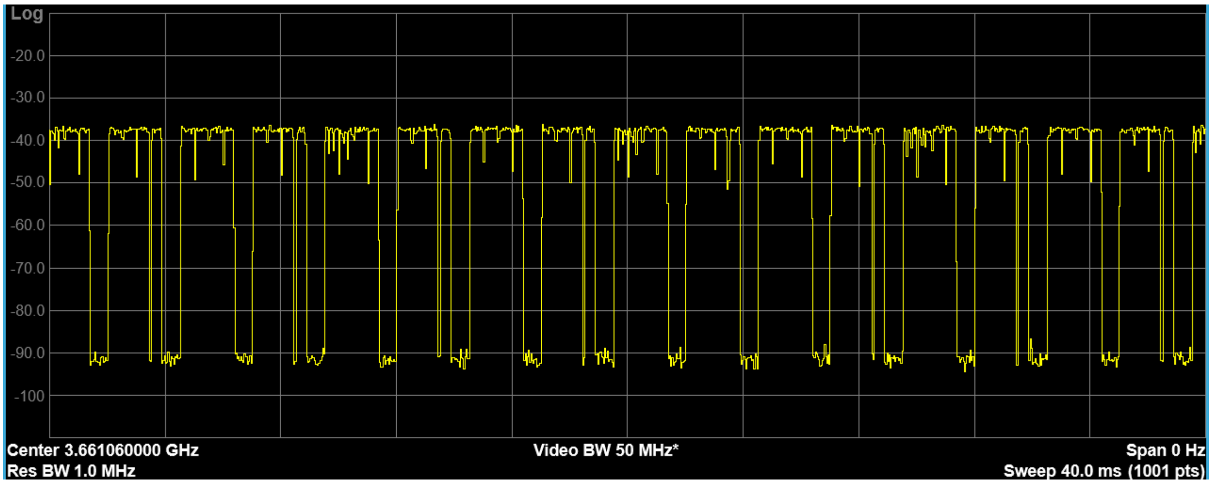


Figure 8: Time vision on 1 MHz at the top of the band around 3661 MHz (therefore outside the SSBs) with continuous downlink traffic over a duration of four frames (40 ms).

4.5.2.3. Measured electric field strengths

On all the sites considered, electric field measurements were taken at a height of 1.5 m at various distances from the antennas, in the 5G antenna frequency band. Except for the Châtillon site, all the measurements were taken outdoors.

In the axis connecting the antenna to the terminal, at a height of 1.5 m, electric field strengths of between 0.25 V/m and 9 V/m were measured, outdoors, at distances ranging from 2 to 250 m from the antennas for transmission over a 100 MHz bandwidth and a maximum transmitted power of 200 W.

- **Bouygues Telecom Huawei site in Mérignac**

On this site, the 64T64R antenna is installed at a height of 8 m on a tree-shaped support. The maximum electric field was measured at this site at about 9 V/m in the vicinity of the CPE served by the antenna.

Figure 9 shows the electric field strength measured at different distances from the 5G antenna, along the CPE axis. Reflections from the ground result in constructive and destructive field combinations which explain the field strength of only 4 V/m at 120 m from the antenna and the field strength of 8.5 V/m at 90 m from the antenna.

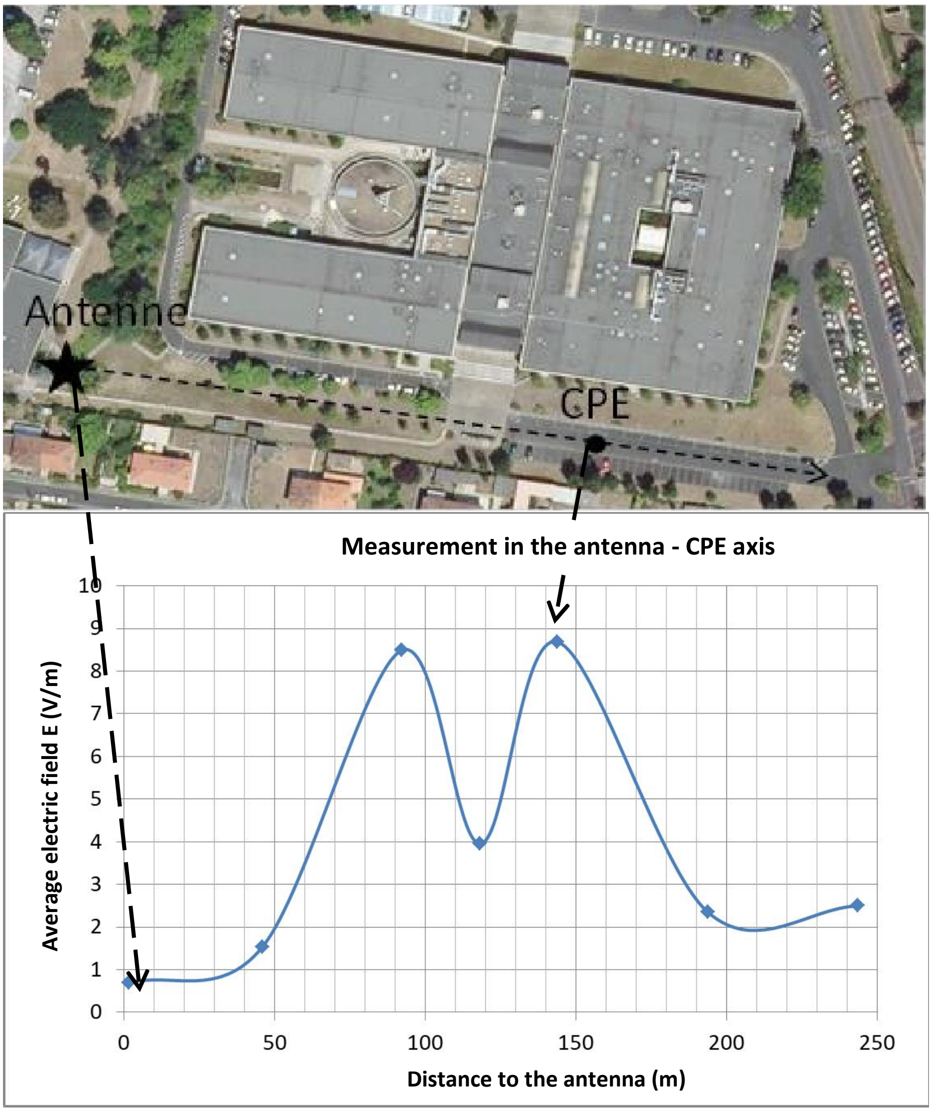


Figure 9: at the top, satellite view of the Mérignac measurement site with the positioning of the antenna, the CPE which received the data sent by the antenna and the measurement axis, at the bottom the illustration of the average electric field assessed over 100 MHz bandwidth at a height of 1m50 depending on the distance to the antenna.

Figure 10 shows the beam width at 1.5 m from the ground and at a distance of 150 m from the antenna. As one moves away from the CPE served by the antenna, the average field strength drops rapidly (by a factor of 2 at 7.5 m on either side of the CPE). On one side of the CPE the reflection of the field on the large building is observed, this reflection causes a field strength of 8 V/m at about 15 m from the CPE compared to a little more than 1 V/m at the same distance from the CPE, but on the other side, with no reflection.

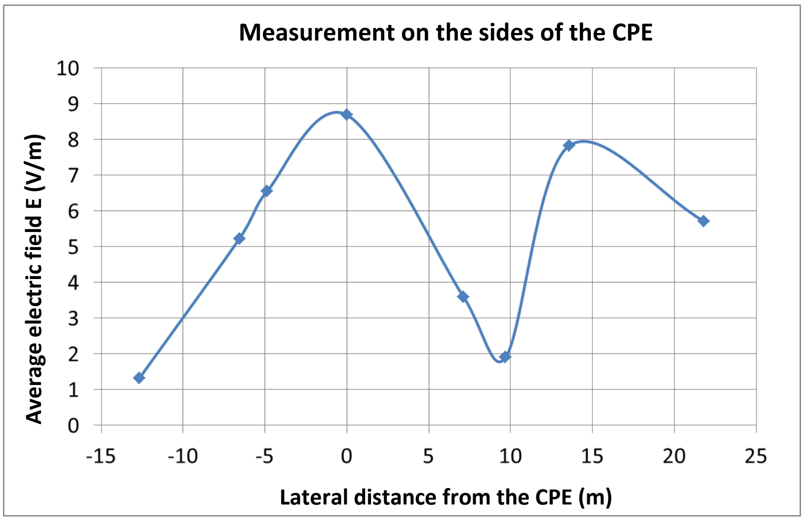


Figure 10: Average electric field strength assessed over 100 MHz bandwidth and measured on both sides of the CPE located at 150 metres from the antenna.

The field strengths measured outside the antenna-CPE axis were between 0.4 V/m and 1.2 V/m for continuous transmission over 50 MHz[5] bandwidth.

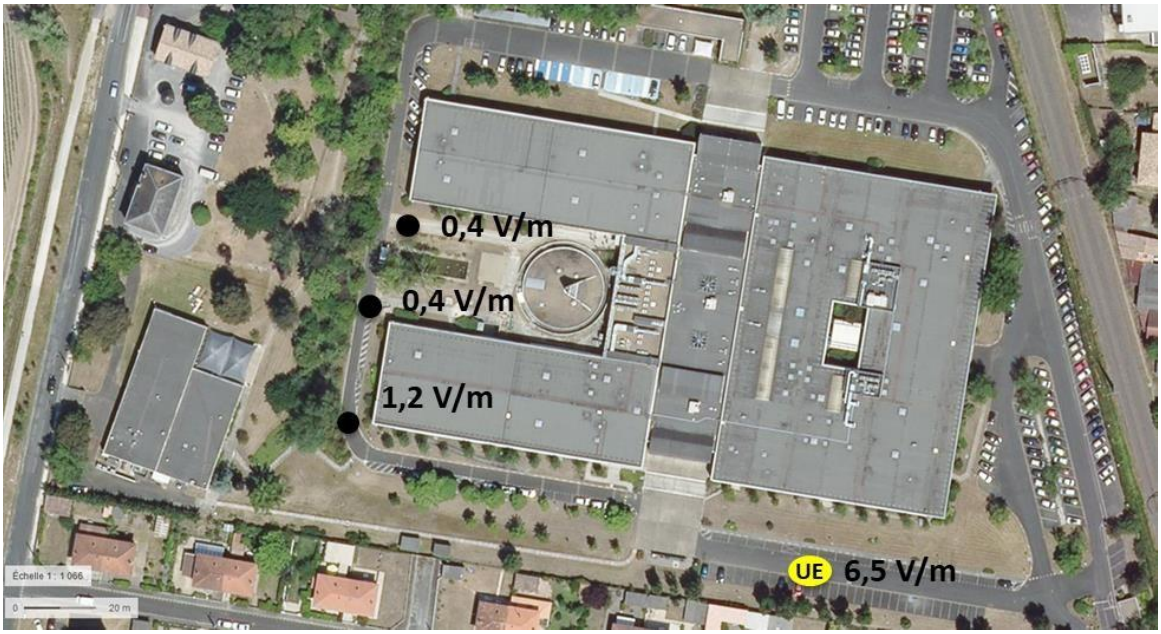


Figure 11: field strength measured outside the antenna transmission axis. In the 50 MHz band axis, the electric field strength was measured at 6.5 V/m.

- **<u>SFR Huawei site in Toulouse</u>**

On this site, the 64T64R antenna is installed on the roof of a building at a height of 27 m. Traffic is continuously established between the antenna and a CPE placed in the line of sight of the antenna (point A on Figure 12). Figure 12 shows the field strengths measured near the CPE and outside the beam axis.

[5] It was not possible to take all the measurements using continuous transmission on 100 MHz due to the limited reception of the CPE used during the tests. In these conditions, the antenna was at 50% of its maximum load.

Figure 12: Satellite view of the Toulouse site with the position of the CPE in red and the field strengths measured in V/m at different points in yellow for a continuous emission over 100 MHz bandwidth with a maximum power of 200 W.

The maximum electric field strength was measured in these conditions on this site at 8.3 V/m three metres from the CPE near a building (see Figure 13). Reflections on this building may explain this higher value than in the immediate vicinity of the CPE.

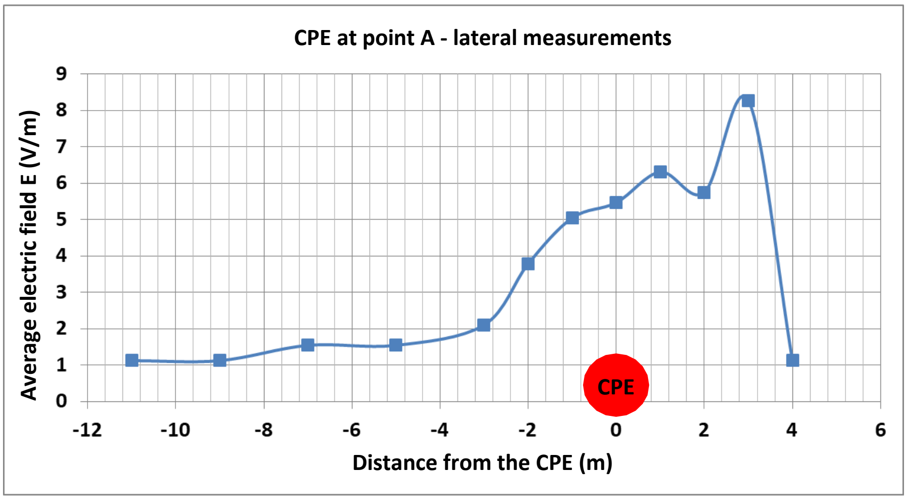


Figure 13: average electric field strength assessed over 100 MHz bandwidth and measured on either side of the CPE located 90 metres from the antenna.

- **<u>Orange Huawei site in Toulouse</u>**

On the Châtillon site, the antenna power was limited to 2 W. It was possible to take indoor measurements near the antenna with the windows open or shut (see Figure 14). The CPE was located near the window, 35 m from the antenna in its median azimuth in one case (left photo in Figure 14) and 7.8 m from the antenna in a very offset azimuth (right photo in Figure 14).

With the windows shut, the field strengths received from the antenna are strongly attenuated, up to a factor of 25 in the immediate vicinity of the antenna (figure on the right).

Figure 14: Indoor measurement points near the Châtillon site antenna, in yellow the field strength in V/m measured with the window open and in blue the field strength in V/m measured with the window shut. On the left, CPE and measurement point at 35 m in the median azimuth of the antenna, on the right CPE and measurement point at 7.8 m from the antenna in a very offset azimuth.

Measurements were also taken outdoors with the CPE placed 60 m away from the base of the antenna: the maximum field strength averaged over 6 minutes and measured over 100 MHz of band in this configuration was 0.65 V/m for 2 W maximum power at the antenna.

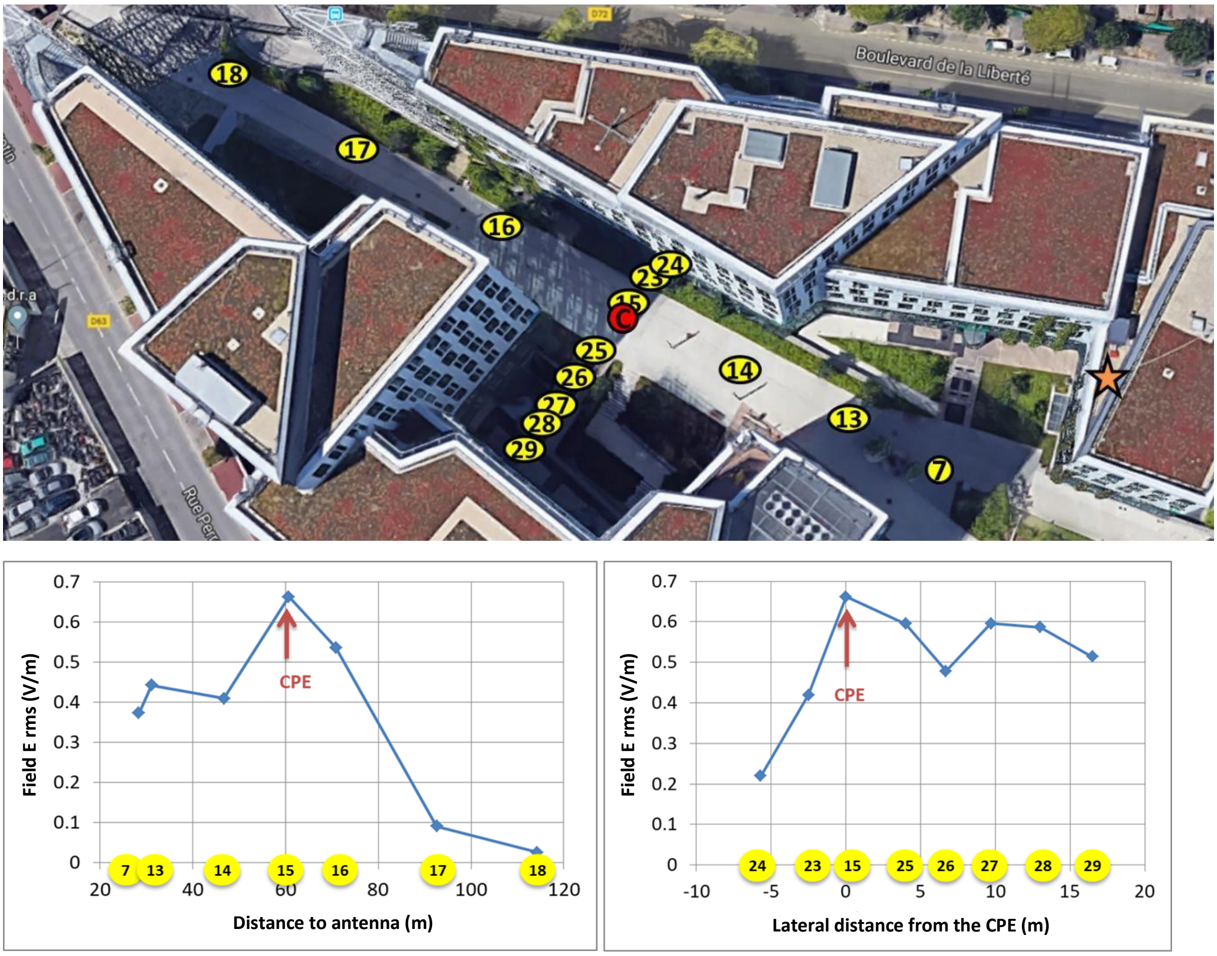


Figure 15: At the top, overhead view of the Châtillon site. The CPE is placed at the red point and the yellow points show the measurement points in the antenna axis and on the sides of the CPE. At the bottom, 6-minute average field strengths measured over 100 MHz band in the antenna axis (on the left) and on the sides of the CPE (on the right).

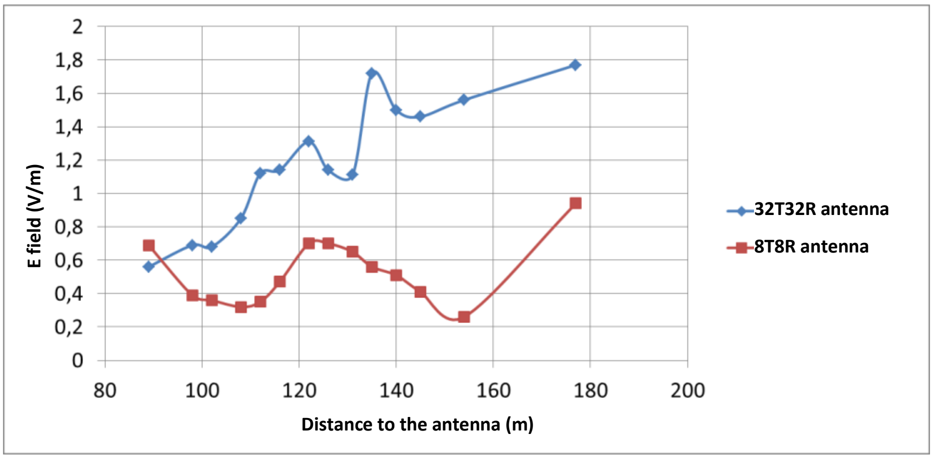
- **<u>Orange Huawei site in Pau</u>**

On this site, the antennas were located on a 45 metre high building and traffic was continuously directed towards a mobile located 125 metres from the antenna, in direct view in a street at the foot of the building supporting the antennas (see Figure 16).

Figure 16: Aerial view of the Pau site with the antennas on a building 45 m high and the CPE located 125 metres from the antenna, in direct view in a street at the foot of the building supporting the antennas. The yellow and orange dots are the measuring points.

On this site, the transmission came from either a 32T32R or an 8T8R antenna. The 8T8R antenna's vertical orientation capability is much lower than that of the 32T32R antenna, which in turn is less than that of a 64T64R antenna.

The maximum field strengths averaged over 6 minutes and measured over 100 MHz band are 1.8 V/m in the case of the 32T32R antenna and 1 V/m in the case of the 8T8R antenna (see Figure 17). Probably neither the mobile nor the measurement points were located in the direct lobe of the antenna, whether in the case of the 32T32R or the 8T8R antenna, which explains the lower field strengths than in other cases, such as in Toulouse or Mérignac for example.



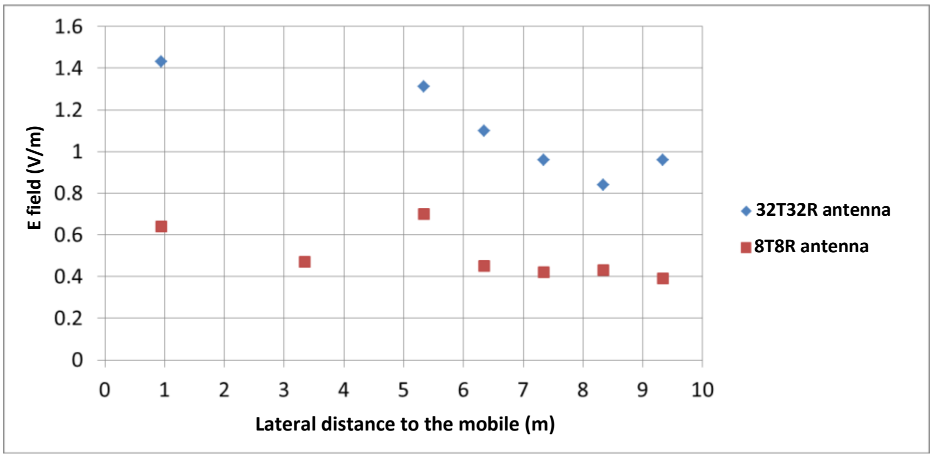


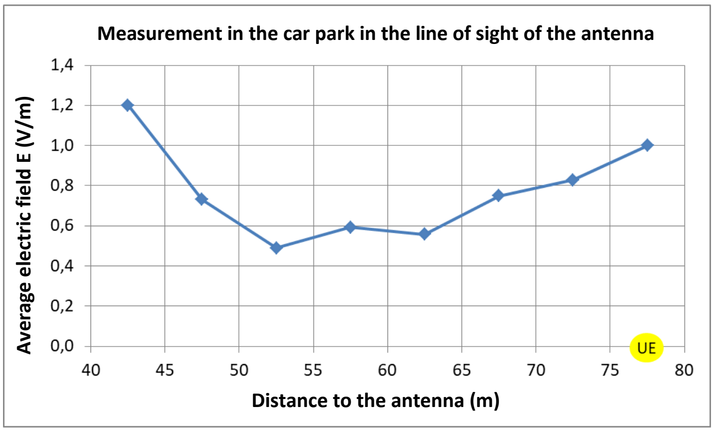
Figure 17: 6-minute average field strengths measured on 100 MHz band in the antenna line-of-sight for the upper figure and on the side of the mobile for the lower figure in the case of continuous transmission from the antenna 32T32R for the blue dots and the 8T8R antenna for the red dots.

- **Orange Ericsson site in Douai**

In Douai, the 64T64R antenna was located on a building at a height of 28 metres and the measurements were taken near the 5G modem in a car park in direct view of the antenna and in its main line of sight (see Figure 18).

Figure 18: Satellite view of the Douai site with the antenna on a building roof, the 5G modem in a car park (orange dot) and the measurement points in yellow.

The maximum 6-minute average field strength assessed over 100 MHz of band is 1.4 V/m on this site in these configurations. The 6-minute average field strengths measured along the axis of the antenna and at the sides of the modem are shown in Figure 19. These field strengths are lower than those observed in similar conditions (such as at the Toulouse site for example). These lower levels are probably due to a lower antenna steering capability and a lower level of gain in the direction of the terminal than the maximum antenna gain.



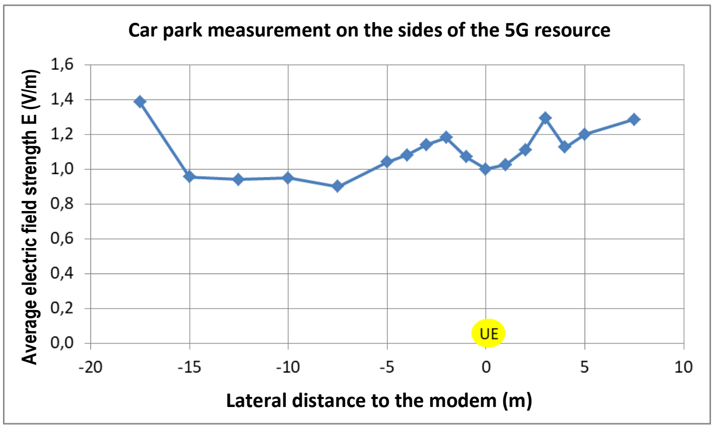


Figure 19: 6-minute average field strengths measured over 100 MHz band in the antenna line-of-sight for the figure at the top and on the side of the 5G modem (UE) for the figure at the bottom.

- **<u>Nokia site in Nozay</u>**

In Nozay, two 64T64R antennas are installed on a 40 metre high building (see Figure 22). One of the antennas (sector 1) is installed on the top floor of the building at a height of 38.5 m and is directed towards a car park with a very high mechanical tilt of 18 degrees. An antenna test mode is used to send traffic continuously and with the antenna at maximum load. Considering the 18-degree tilt, the antenna's line of sight fires at about 124 metres from the antenna.

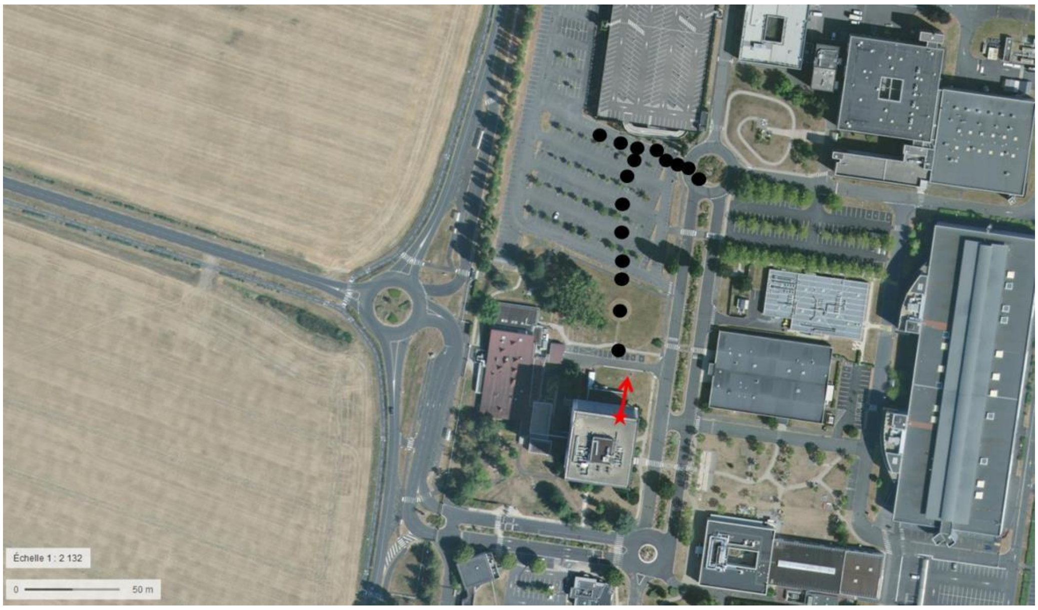


Figure 20: aerial view of the Nozay site and sector n°1 pointing towards a car park, the measurement points are shown in black. The antenna and its line of sight are shown in red.

The maximum 6-minute average field strength assessed over 100 MHz of band is 6 V/m in this sector and these configurations. Figure 21 shows the field strengths measured in the line of sight of the antenna and perpendicular to it. A building located about 150 m from the antenna can explain the field variations between 130 and 140 m in the line of sight of the antenna.

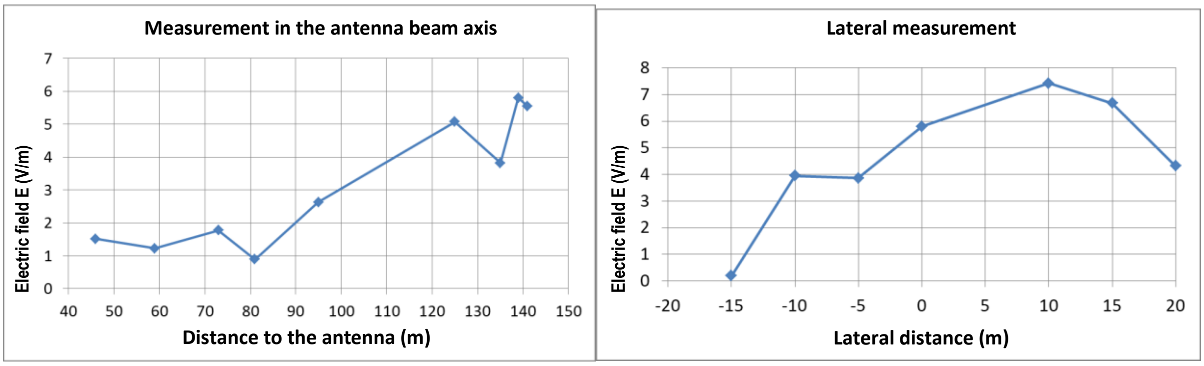


Figure 21: 6-minute average electric field strengths measured at sector 1 of the Nokia site in Nozay on the left in the line of sight of the antenna and on the right perpendicular to the line of sight of the antenna at about 140 metres from the antenna.

The other antenna (sector 4) is installed on the roof of the building at a height of 41.5 m and is directed towards fields with a mechanical tilt of 8 degrees (see Figure 22). The antenna test mode makes it possible for data to be transmitted in a tilted beam of 18 degrees (8 degrees mechanical and 10 degrees electrical) which therefore theoretically fires at 134 m from the antenna.

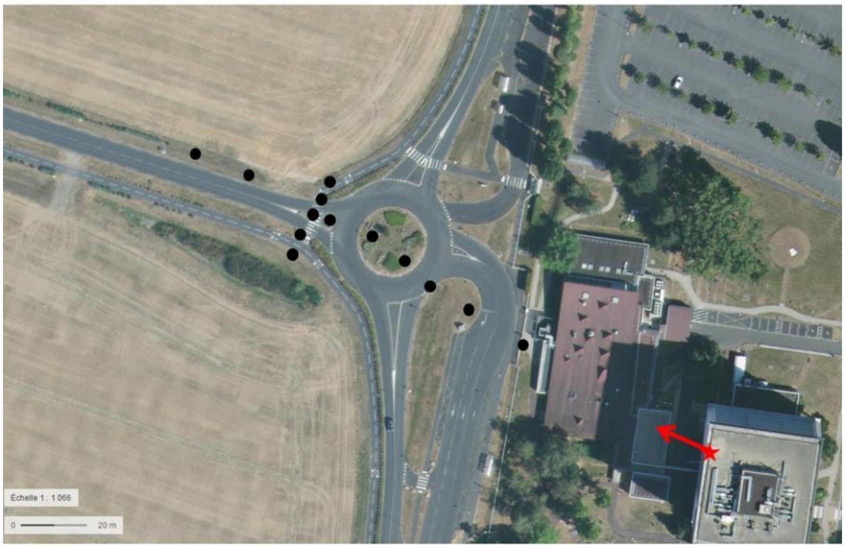


Figure 22: Sector 4 of Nokia's site in Nozay with an antenna installed at a height of 41.5 metres (shown in red in the picture) and measuring points shown in black in the picture.

The maximum 6-minute average field strength assessed over 100 MHz of band is 3.5 V/m in this sector and these configurations. This electric field strength is lower than in sector 1 because of the electrical tilt which causes gain losses. Figure 23 shows the field strengths measured in the line of sight of the antenna and perpendicular to it.

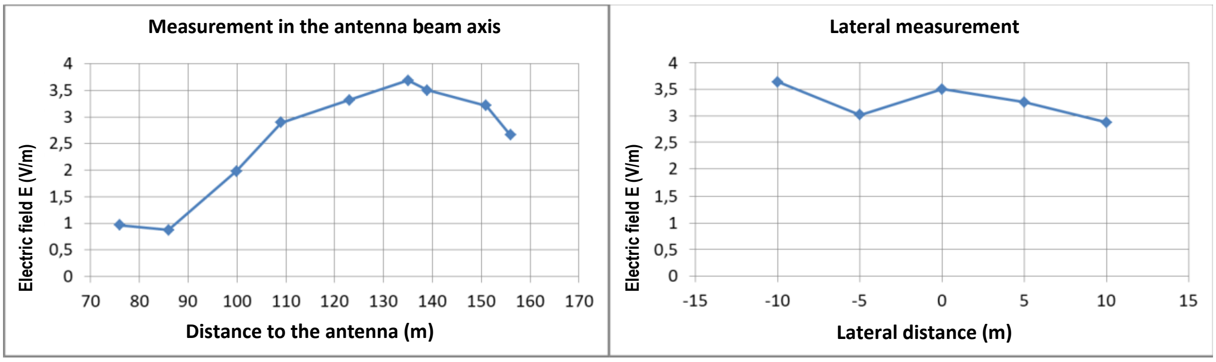


Figure 23: 6-minute average electric field strengths measured at sector 4 of the Nokia site in Nozay on the left in the line of sight of the antenna and on the right perpendicular to the line of sight of the antenna at just under 140 metres from the antenna.

4.5.3. With file transfer

In this configuration, exposure is triggered by a file download requested by the CPE, the modem or the mobile phone. Different file sizes from 150 MB to 10 GB were used. As a reference, a measurement without traffic, i.e. without downloading, was also taken, as well as a measurement in the configuration discussed in the previous paragraph, i.e. with a continuous transmission at full antenna load in the direction of the equipment (infinite case in the following tables).

Table 6, Table 7 and Table 8 summarise the field strengths measured over 6 minutes in the vicinity of the equipment receiving the files of different sizes for the 3 sites where this configuration was processed.

Download time	File Size	Average E over 6 minutes
No downloads	0 MB	0.2 V/m
2 s	150 MB	0.5 V/m
7 s	500 MB	0.8 V/m
15 s	1 GB	1.1 V/m
150 s	10 GB	3.9 V/m
Infinity	Infinity	6.5 V/m

Table 6: Average field strengths measured over 6 minutes near a CPE downloading files of different sizes from the Huawei Bouygues Telecom site in Mérignac. The infinite case corresponds to a continuous data transmission at full antenna load to the equipment.

Download time	File Size	Average E over 6 minutes
No downloads	0 MB	0.28 V/m
19 s	1 GB	1.6 V/m
190 s	10 GB	4.8 V/m
Infinity	Infinity	8.2 V/m

Table 7: Average field strengths measured over 6 minutes near a CPE downloading files of different sizes on the Nokia site in Nozay. The infinite case corresponds to a continuous data transmission at full antenna load to the equipment.

Download time	File Size	Average E over 6 minutes
No downloads	0 MB	0.2 V/m
2 s	150 MB	0.3 V/m
7 s	500 MB	0.6 V/m
14 s	1 GB	0.8 V/m
134 s	10 GB	2.4 V/m
Infinity	Infinity	3.9 V/m

Table 8: Average field strengths measured over 6 minutes near a CPE downloading files of different sizes on the Huawei SFR site in Toulouse. The infinite case corresponds to a continuous data transmission at full antenna load to the equipment.

The exposure level is assessed over 6 minutes and therefore depends mainly on use. By way of comparison, a typical current monthly 4G 10 GB package could be used up in about 150 s (2 min 30 s) in the test conditions.

5. Outlook

5.1. Exposure indicator

The measurement of exposure in the field in particular fulfils a need for information on the levels of exposure encountered on a daily basis. For mobile telephony, with the technologies currently deployed and current uses, the level measured with a broadband probe (case A of the ANFR measurement protocol) during the day, regardless of the time of day, is a good indicator of exposure, generally close to that which would be observed by taking continuous measurements averaged over six minutes: in fact, the amplitude of the variations during the day observed in the studies is generally low, at less than 30%.

With 5G steered beam antennas, greater spatial and temporal variability is foreseeable and the level read at the broadband probe at any given time may no longer be a good indicator of exposure. The level of exposure will indeed highly depend on the use, and in particular on the data calls made by the terminal.

A new indicator is therefore proposed, based on the foreseeable use of 5G: one gigabyte of data sent in a given direction every 6 minutes. Assuming an average rate of 500 Mbps, the antenna will only transmit in the given direction for about 15 seconds out of the 6 minutes (about 4% of the time). This indicator has been included in the national guidelines on the presentation of simulation results of exposure to waves emitted by radio installations.

Assuming 8 active beams to serve the antenna coverage area, the area covered by the antenna will thus receive an average of 8 GB every 6 minutes, which corresponds to 960 GB per day assuming 12 hours of network use per day, and 28,800 GB per month. There were 47.7 million 4G SIM cards in France at the end of 2018 and nearly 40,000 4G sites in service, which means that the average number of users per site can be estimated at 1,000. Using these assumptions, the monthly 5G consumption would be 28 GB per month. By way of comparison, the average 4G consumption in the last quarter of 2018 was 7 GB per month on average: taking into account the fourfold increase in consumption currently observed, this volume takes into account the change in uses that seems likely to be brought about by 5G.

The assumptions used to define this indicator will be compared with the exposure measurements in the field for the 5G commercial networks and will be revised if necessary, particularly in the event of an increase in data consumption.

The interest of this indicator is that it makes it possible to calculate exposure in real conditions by applying a reduction factor in relation to theoretical maximum antenna power.

Currently, in the national guidelines on the presentation of simulation results published by the ANFR[6], a factor of 1.6 (i.e. 4 dB in power) is applied to the calculated electric field strength to account for statistical variations over 6 minutes for fixed beam antennas.

[6] https://www.anfr.fr/fileadmin/mediatheque/documents/5G/consultation/consultation-5G-Lignes-directrices-national.pdf

For *indoor* use, it is supplemented by a factor of 20% (i.e. 2 dB in power) to take into account the attenuation by single glazing.

For 5G, several factors will apply:

- the TDD ratio, as the antennas do not transmit continuously and provide listening ranges to receive signals from terminals: typically 75% power (i.e. 1.25 dB);
- the statistical variations over 6 minutes in the case of variable-beam antennas: considering the high beam mobility, which must constantly scan the entire sector covered by the antenna in order to serve the terminals located there: these are reflected by a power ratio of 4% (i.e. 13.5 dB);
- Attenuation through glazing: identical to 4G, 20% in field (i.e. 2dB in power)

This indicator results in a reduction factor which makes it possible to calculate the exposure in real conditions using the theoretical maximum antenna power.
The field strengths at 100 metres from a 5G antenna resulting from the application of the indicator appear to be comparable to those found at the same distance from a 4G antenna (see Table 9).

4G	Current	Future
Maximum power	60 W	160 W
Maximum antenna gain	18 dBi	18 dBi
6-minute attenuation	- 4 dB	- 4 dB
Glazing	- 2 dB	- 2 dB
E field estimated at 100 m	**1.7 V/m**	**2.8 V/m**

Table 9: Estimated electric field strength at 100 metres from a 4G antenna inside a building with a typical current power assumption and a future power assumption.

5G	Low assumption	High assumption
Power	80 W	200 W
Gain	24 dBi	24 dBi
6-minute attenuation	- 13.5 dB	- 13.5 dB
Glazing	- 2 dB	- 2 dB
TDD	- 1.25 dB	- 1.25 dB
E field estimated at 100 m	**1.1 V/m**	**1.8 V/m**

Table 10: Estimated electric field strength at 100 metres from a 5G antenna inside a building with a low power assumption and a high power assumption.

However, for 4G, the reduction factor applies to the maximum antenna gain value which is only measured in the main antenna direction: outside this main direction, the field strength will be lower. On the other hand, with 5G steered beam antennas, the exposure calculated using the indicator will be valid in a higher number of directions

5.2. Safety perimeters

When installing radio sites, mobile operators must install safety perimeters around the radio base stations outside of which the level of exposure of the general public to the electromagnetic fields emitted by radio installations is below the limit values.

The ANFR publishes an informative guide that establishes practical rules for the installation of radio sites[7].

For currently deployed technology, the mobile phone operators use the theoretical maximum power to determine the safety perimeters, without taking into account possible variations over 6 minutes. This simplified approach is therefore independent of the duration.

With the use of steered beam antennas, spatial and temporal variability is expected to increase and this approach no longer seems appropriate.

The proposed solution, in particular in the IEC[8] standardisation groups, is to use the maximum 6-minute average power to determine the safety perimeters instead of the maximum peak power. However, the use of this maximum 6-minute average power to determine safety perimeters is subject to the availability of tools to make sure that the 6-minute average power used to calculate safety perimeters is never exceeded in the field.

[7] https://www.anfr.fr/fileadmin/mediatheque/documents/sites/2018-05-07_ANFR-DR17-5_Guide_Périmètres_de_Sécurité_VF.pdf

[8] IEC TR 62669:2019 Case studies supporting IEC 62232 - Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure

6. Conclusions

These initial measurements covered several antenna configurations (different brands of antenna, different sizes) and different implementations of 5G NR (for example with a different number of SSBs or different frame formats).

The levels of the measured fields are all well below the regulatory limit value of 61 V/m in the 3.4 - 3.8 GHz frequency band.

The measurements taken have confirmed that the exposure to the waves depends on many parameters, including:

- the distance between the antenna and the terminal, which is classic;
- the beam focus and the number of beams controlled by the antenna;
- the duration of presence of the beam in each direction and therefore of the data requests by the terminals in the beam.

These first measurements were taken in special configurations allowing good control of the measurement conditions. These configurations were implemented because the networks were not open to the operators' customers. After the networks have been opened to the operators' customers, new measurements will make it possible to test more realistic configurations in terms of traffic and to supplement the conclusions of this report.

Furthermore, these measurements concerned almost exclusively outdoor measurements. Indoor measurements will complete the analysis.

Finally, this study focused on the 3.4 - 3.8 GHz band, which will be the first to be used for 5G in France. Initial experiments in the 26 GHz band were authorised by ARCEP at the end of 2019. 5G will also need to be studied in this new frequency band.