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Campagne nationale de mesure pour l'étude de la contribution de la 5G à l'exposition du public aux ondes électromagnétiques
National measurement campaign to study the 5G contribution to public exposure to electromagnetic waves

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Résumé
Dans le cadre de ses missions de surveillance de l'exposition du public aux ondes électromagnétiques, l'Agence nationale des fréquences (ANFR) a lancé un vaste programme de mesures sur près de 2 000 sites pour évaluer l'exposition à la suite du déploiement de la nouvelle technologie mobile 5G dès fin 2020. Pour chaque site identifié dans le programme, une mesure initiale est réalisée avant le rajout de la 5G sur ces sites, une deuxième et troisième mesure sont réalisées à environ 4 mois et 8 mois de mise en service dans le but de suivre l'évolution de l'exposition en fonction du déploiement opérationnel et de l'accroissement du trafic. Les mesures sont réalisées selon le protocole de l'ANFR référencé au Journal Officiel, constituant le texte de référence des laboratoires accrédités qui réalisent des mesures sur le terrain (E in situ). En complément des mesures d'exposition globale et détaillées en fréquences, des mesures spécifiques ont été effectuées en téléchargeant un fichier de 1 Go sur la bande 3 500 MHz. Ce mode opératoire permet de générer artificiellement un trafic supplémentaire correspondant à l'indicateur d'exposition proposé par l'ANFR pour les antennes à faisceaux orientables et permet d'estimer le niveau d'exposition local qui serait statistiquement atteint à terme en 5G.

Abstract
As part of its missions to monitor public exposure to electromagnetic waves, the French national frequency agency (ANFR) has launched an extensive measurement program at nearly 2 000 sites to assess exposure following the deployment of the new 5G mobile technology starting in late 2020. For each site identified in the program, an initial measurement is performed before the addition of 5G on these sites, a second and third measurement are performed at about 4 months and 8 months of operation in order to monitor the evolution of exposure according to the operational deployment and traffic growth. The measurements are carried out according to the ANFR protocol referenced in the French official journal, which is the reference text for accredited laboratories that carry out field measurements (E in situ). In addition to the global and detailed frequency exposure measurements, specific measurements were performed by downloading a 1 GB file on the 3 500 MHz band. This procedure allows to artificially generate additional traffic corresponding to the exposure indicator proposed by ANFR for steerable beam antennas and allows to estimate the local exposure level that would be statistically reached in the long term in 5G.

1 Introduction

5G is now being deployed in mainland France on several frequency bands, the so-called low frequency bands 700 MHz and 2100 MHz, which have been used for many years by previous generation mobile phone networks (3G and 4G), and the new 3500 MHz band, which offers a wider bandwidth for higher data rates.

The French frequency agency (ANFR) ensures compliance with the limit values for public exposure to electromagnetic waves set by decree [1]. To this end, it develops and updates the exposure measurement protocol. As part of its mission to monitor public exposure, the ANFR has launched a vast program of in situ electric field measurements to characterize the influence of 5G on exposure levels. This vast program covered nearly 2 000 radio sites throughout metropolitan France. Three phases were carried out from the end of 2020 to the end of 2021 on sites identified to host 5G: an initial measurement before the arrival of 5G on these sites (phase 1), a second measurement carried out about 4 months after the start of service (phase 2) and finally a third measurement at an interval of about 8 months (phase 3). This campaign continued in 2022 with 2 additional phases.

This paper will focus on the results through the end of 2021 of the 5G sites operating in the 3 500 MHz band.

2 Measurement protocol and locations

2.1 Measurement protocol

The current ANFR version 4 measurement protocol was used [2]. Since 2001, ANFR is in charge of defining and updating in situ measurement protocol to check if RF general public exposure levels are in compliance with French exposure limits. The ANFR protocol is referenced in the French official journal [3] and used by ISO IEC 17025 [4] accredited laboratories. It is in line with international EN IEC 62232 [5] standard section 6.3 “Evaluation processes for in-situ RF exposure assessment”.

A global measurement of the exposure is made with the broadband probe (case A). A detailed measurement (case B) can then be carried out to specify the exposure for each frequency band and for each operator. In the framework of this campaign, case B was not systematically carried out on each measurement point. During the second phase of measurements in 2021, it was carried out, for the most part, only for points where the global level was greater than or equal to 2 V/m.

Case A takes into account all significant radio sources and frequencies between 100 kHz and 6 GHz. It is based on the use of a broadband probe. This probe has a sensitivity of 0.38 V/m. Case B involves the use of a spectrum analyzer and provides a detailed measurement of each exposure contribution in this same frequency range. The spectrum analyzer has a minimum sensitivity of 0.05 V/m, depending on the frequency bands. It should also be remembered that, according to the ANFR protocol, emissions are only considered significant if their level is at least 0.3 V/m.

All measurements were performed outdoors and during the day, in direct view of the main lobe of the antennas and at a distance of about 100 m. Figure 1 shows a typical configuration of this campaign.

Figure 1 : Typical configuration of measurement

With current uses on the technologies deployed previously (2G, 3G and 4G), the level measured with the broadband probe (case A) during the day, regardless of the time of day, is a good indicator of exposure, generally close to the level observed by making continuous measurements averaged over six minutes: the amplitude of variations during the day observed in the studies is generally low, less than 30%. However, with the 5G steerable beam antennas, greater spatial and temporal variability is expected, this is why the level measured with a broadband probe at any one time may no longer be a good indicator of exposure. The exposure level will strongly depend on the usage, and in particular on the data request made by the terminal. For this purpose, the ANFR proposed in [6] a new indicator, based on a foreseeable use of 5G. This consists in sending in a given direction 1 GB of data every 6 minutes. Assuming an average data 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).

At the beginning of a new technology deployment, its load is low, especially because few users have the appropriate terminals and subscriptions. Thus, at the launch of 5G in the 3.4 - 3.8 GHz band used exclusively for 5G, the levels measured were very low, as expected, because the 5G network would be very lightly loaded. In order to measure an exposure level which may be more representative of that eventually generated by 5G in the long time, the ANFR opted to voluntarily solicit the 5G antennas by downloading a 1 GB file to consider a realistic antenna load in accordance with the assumptions taken for the definition of the exposure indicator described above.

The measurement consists in performing two evaluations: when the network is not voluntarily solicited and when it is solicited by a mobile by downloading a 1 GB file from a server by ensuring that the server's performance allows for the expected 5G speeds (on average 500 Mbps) at the measurement point. Il is also necessary to ensure that the download is performed on the 3 500 MHz band.

It is worth noting that the RMS electric field level averaged over 6 minutes without network solicitation can be evaluated over a period of under 6 minutes as long as the averaged RMS value is stable. The RMS electric field level averaged over 6 minutes can then be evaluated from the measurement averaged over the duration of the download according to the following equation:

$$E_{estim\_6min} = \sqrt{\left(\frac{T_t}{360}\right) \times E_{at}^2 + \left(1 - \frac{T_t}{360}\right) \times E_{st}^2} \qquad (1)$$

Where:
E_{estim_6min} : Field strength in V/m averaged over 6 minutes
T_t : Duration in seconds of the 1 GB file download
E_{at}: Average field strength in V/m measured during the download time
E_{st} : Average field strength in V/m measured in the absence of artificial network load

2.2 Measurement locations

The distribution of 5G sites in mainland France is shown in Figure 2 (a)[1], 85% of the sites are located in urban areas and 15% in rural areas (Figure 2 (b)). This distribution is close to the proportion of the urban population in the total population in France (80% in urban areas)[2].

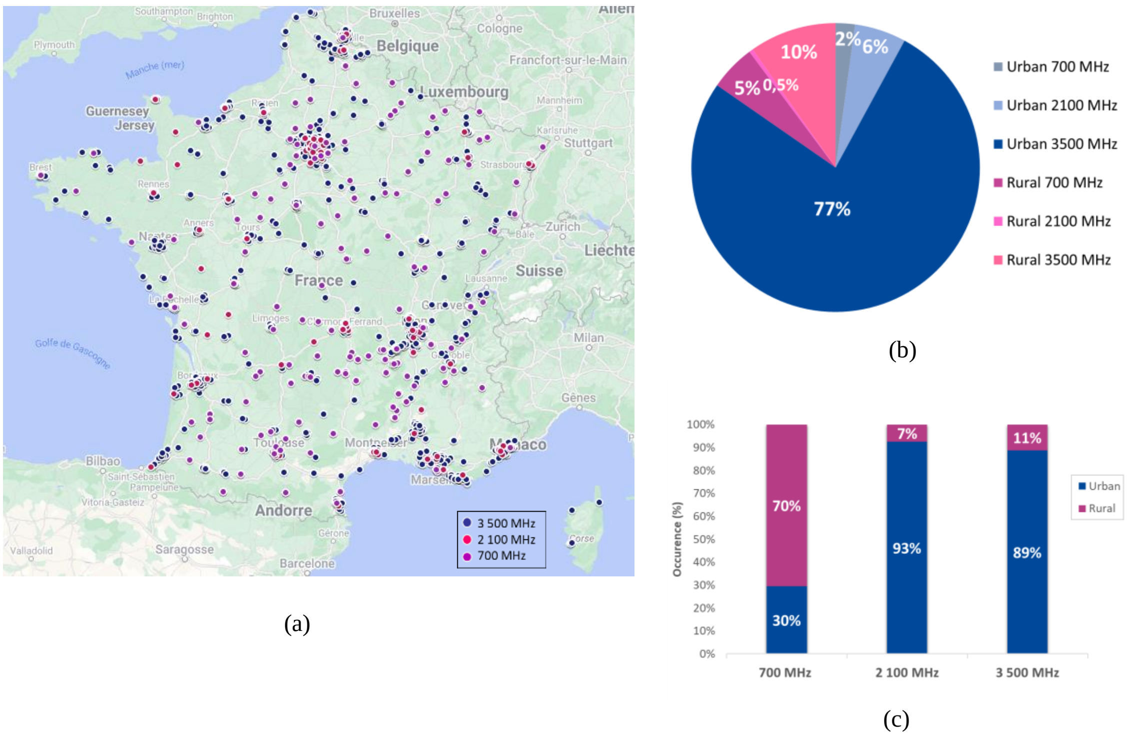

Figure 2 : (a) Geographical distribution, (b) Environment type distribution, (c)Frequency bands distribution

For the remainder of this papier, a measurement performed before the commissioning of 5G will be noted as a "before" measurement representing phase 1, the one performed after about 4 months of commissioning of 5G will be noted as a "after 1" measurement representing phase 2 and the one performed after about 8 months of operational deployment will be noted as a "after 2" measurement which concerns phase 3. A pair of measurements before and after the activation of 5G will be noted "before/after 1" or "before/after 2" depending on the phase of the campaign considered. A trio of measurements representing the 3 phases of the campaign will be noted "before/after 1/after 2".

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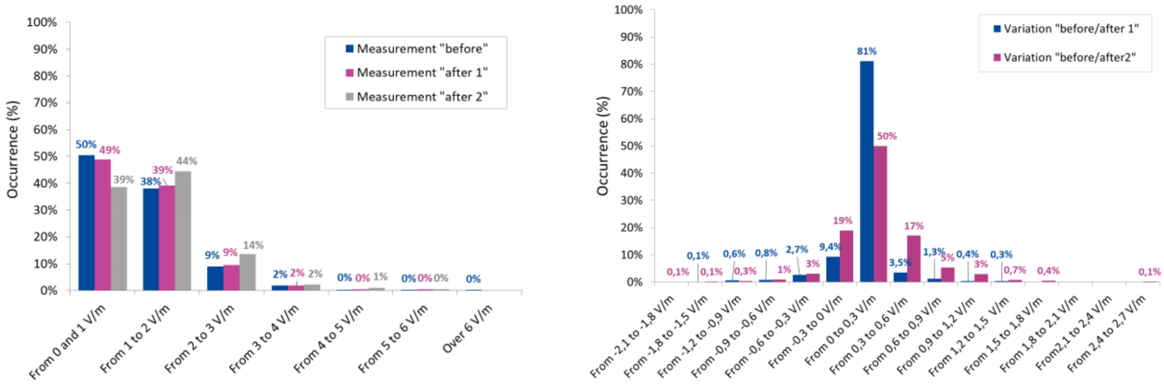
[1] In 2022, the ANFR continued its program in the DROM-COM with a campaign launched in Reunion Island.
[2] https://www.insee.fr/fr/statistiques/4806684

3 Results

3.1 Analysis of overall exposure levels

The analysis of overall exposure levels (case A) is studied in this section on around 1360 sites hosting 5G on the 3 500 MHz band. Figure 3 (a) shows the distribution of measurements by 1 V/m increments on the overall exposure levels observed before and after the activation of 5G during phases 2 and 3 of the campaign.

Theses histograms shows that exposure remains steady between Phases 1 and 2. This trend has changed in Phase 3, where an increase is observed. Indeed, it appears from the histograms plotted in Figure 3 (a) that 11% of the points that were in the "from 0 to 1 V/m" range in phase 1 leave this range and move towards the higher ranges because they become more exposed. However, this increase is moderate, as can been see 83% of the "after 2" measurements remain under than 2 V/m, compared with 88% of the "before" and "after 1" measurements.



(a) (b)

Figure 3 : (a) Distribution of overall exposure levels before and after 5G roll out on 3,6 GHz band; (b) Distribution of differences between overall exposure levels before and after 5G roll out on 3,6 GHz band

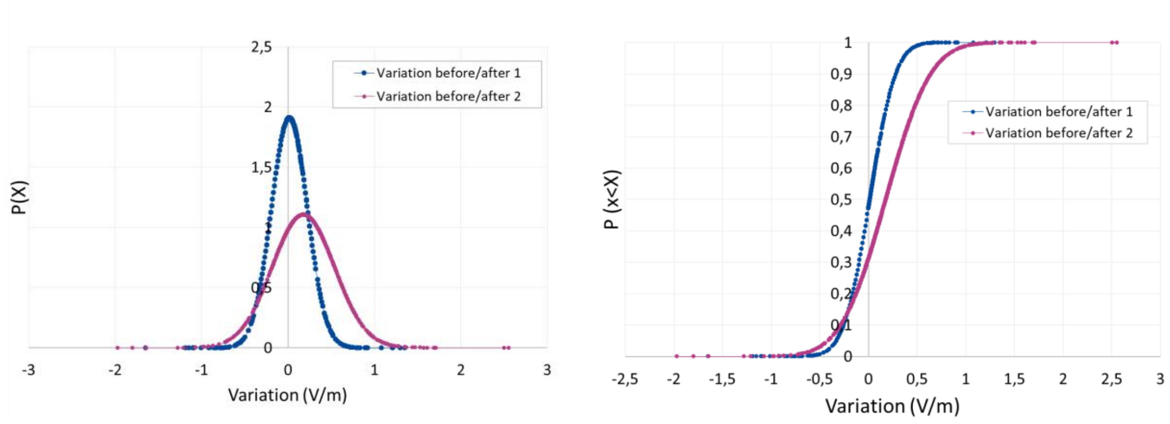
Comparison of the statistical parameters shown in Table 1 confirms this first conclusion. The average exposure level is 1.16 V/m for the "before" measurement, 1.17 V/m for the "after 1" measurement and 1.34 V/m for the "after 2" measurement, i.e., an average variation that increases from 0.01 V/m (close to zero) for phase 2 to 0.18 V/m for phase 3.

	Nb measurements	Mean (V/m)	Median (V/m)	Std Deviation (V/m)	Max (V/m)
Overall exposure « before»	1 358	1.16	0.99	0.75	6.19
Overall exposure « after 1 »	1 358	1.17	1.01	0.74	5.41
Overall exposure « after 2 »	1 358	1.34	1.19	0.79	5.83
« before/after 1 » Variation		0.01	0.02	-0.01	-0.78
« before/after 2 » Variation		0.18	0.2	0.04	-0.36

Table 1 : Comparison of overall exposure filed level statics before and after 5g roll out

In order to better characterize the variation between the "before" and "after 1/after 2" measurements, the local variation is studied to observe how the electric field levels are distributed locally (i.e. site by site). For this purpose, the statistical distribution of the differences between the trio of "before/after 1/after 2" measurements is characterized in Figure 3 (b) by histograms of 0.3 V/m increments and modeled by the normal distribution probability density and its cumulative distribution function (CDF) in Figure 4.

The histograms show a greater variation in phase 3 than in phase 2, where in more than 90% of cases, the variation was between -0.3 V/m and 0.3 V/m (non-significant and below the sensitivity of the probe), compared to 69% in phase 3. It is quite clear to observe from probability density and CDF that the distribution of the "before/after 2" variation is no longer centered on zero as it is for the "before/after 1" variation. It also shows that the 90% and 99% values are larger for the "before/after 2" variations.



(a) (b)

Figure 4: Probability density function (a) and cumulative distribution function (b) of differences between overall exposure levels before and after 5G roll out on 3 500 band

The results conclude that 4 months after the introduction of 5G, there was no significant change in overall exposure compared to before its activation. However, 8 months after the commissioning of 5G, there was an increase compared to before the introduction of 5G, with an average overall exposure value that rose from 1.16 V/m to 1.34 V/m.

It should be further noted that at this stage of the study, it is not possible to identify which frequency band contribute to this increase, as only the global exposure was studied. The detailed frequency measurements (case B) which will be discussed in the next section allow us to obtain a comprehensive exposure evaluation with frequency selective equipment enabling the identification of the sources contributing to the exposure.

3.2 Analysis of the contribution levels of the 3 500 MHz band

In order to analyze this increase more closely, the detailed frequency measurements (case B) will be discussed by isolating the contribution of the telephony service in the 3 500 MHz band but also in the other frequency bands. Among the 1 358 sites analyzed previously, 141 of the most exposed (if at least one measurement has an overall value of 2 V/m) were covered by detailed measurements during phases 2 and 3 of the campaign.

First, the Figure 5 (a) shows the most contributing service to the overall exposure, where it can be seen that the 800 MHz and 900 MHz bands are the main contributors in about 55% of the cases in both phase 2 and phase 3. It appears that the 2100 MHz band becomes the main contributor in 9% of cases in phase 3, where it was at 1% during phase 2. The 3 500 MHz band is not the main contributor in phase 3, so it could not a priori be the cause of the increase in overall exposure.

Secondly, in order to better represent exposure by service, the histograms in Figure 5 (b) show the increase in average exposure, particularly for mobile services, between phases 2 and 3. The increase in average exposure per frequency band is relatively significant at frequencies where LTE (4G) is present (TM_1800 and TM_2100). For the 3 500 MHz band, it is not possible to conclude that there is an increase, as the levels are not significant. It is important to point out that the levels recorded remain very low compared to the regulatory limit values (36 V/m for the lowest mobile telephony band and 61 V/m for the highest band).

At least, these selective E field measurements show that the increase observed on the overall exposure is not due to an increase in field strength on the 3 500 MHz band, but to an increase in exposure on the other cell phone bands, especially the bands allocated to 4G.

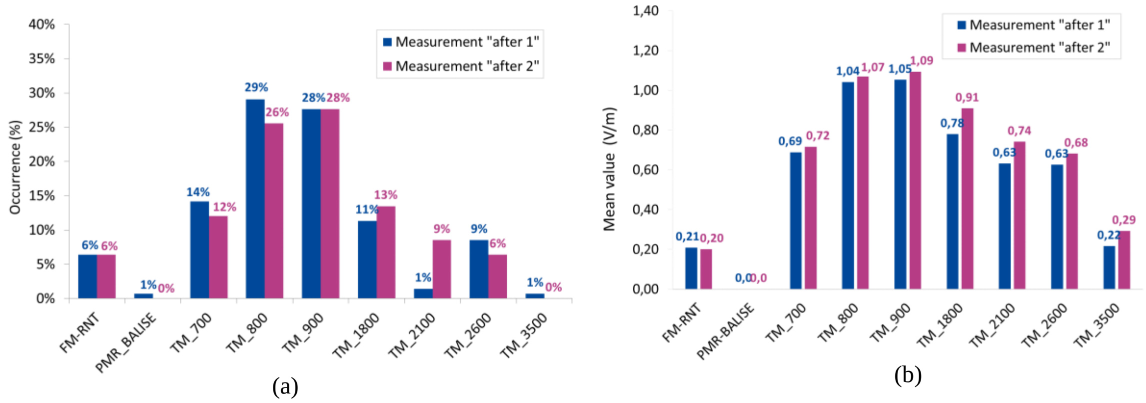


Figure 5 : Distribution of main contributions to overall exposure (a) by service/ frequency band and evolution of their mean value (b) (FM-RNT: Radio broadcasting, PMR-Balise: Private Mobile Radio, TM: Mobile Telephony (cellular network))

3.3 5G specific measurements with data download

At the launch of the campaign, few users are soliciting 5G antennas, so it seemed interesting to artificially create traffic to study the effect of 5G on overall exposure by simulating higher usage in this band. As described in the protocol part, the traffic is generated by downloading 1 GB of data, which corresponds to the exposure indicator proposed by ANFR. In this section, the measurements of 464 sites will be studied.

The Figure 6 shows, in grey, the average field strength during the download of the 1 GB file on the 3 500 MHz band, and the levels over 6 minutes with and without artificial downloading in pink and blue respectively. The levels shown here are the maximum levels observed between phases 2 and 3.

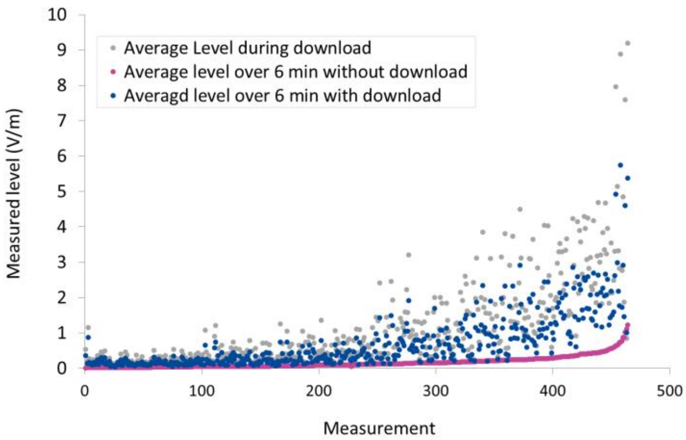


Figure 6 : Average field strength while downloading a 1 GB file compared with the average level without downloading on the 3500 MHz band

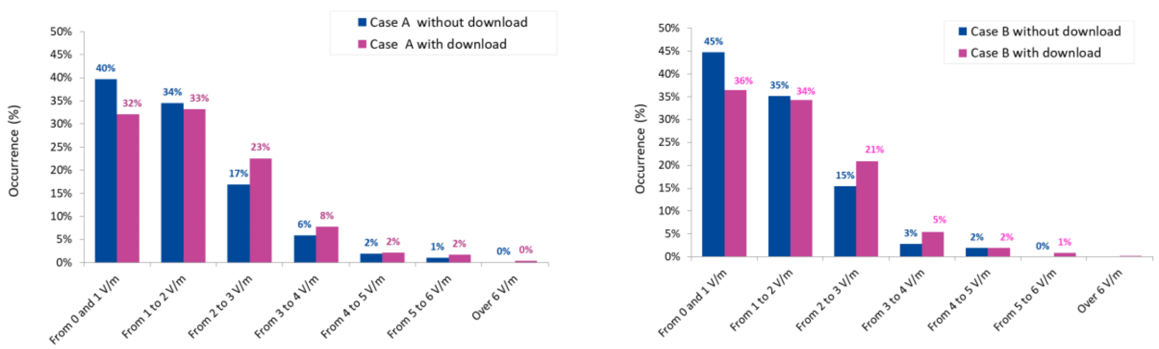
The average increase calculated between the measurement on the 3 500 MHz band with artificial download averaged over 6 minutes (in blue) and the average level without download (in pink) on this same band is 0.54 V/m. The average level calculated due to the single download of the 1 GB data file is 0.68 V/m close to 0.70 V/m which corresponds to the average level of measurements with download including existing traffic, meaning that there is not yet significant traffic in this band.

The Table 2 gives the statistics calculated on the 3 500 MHz band with and without artificial downloading.

	Number of measures	Average (V/m)	Median (V/m)	Standard deviation	Max (V/m)
Exposure on the band 5G 3 500 MHz without download	464	0.16	0.10	0.16	1.22
Exposure on the band 5G 3 500 with download	464	0.70	0.38	0.79	5.75
Variation with and without download (V/m)		0.54	0.28	0.63	4.53

Table 2 : Statistics on the 3 500 MHz band with and without downloading

To evaluate the impact on the global exposure level, the average level over 6 minutes related to the download of the isolated 1 GB file, resulting from the specific measurement with 5G artificial solicitation, is integrated by calculation to the global exposure case A and the overall cumulative exposure case B without specific solicitation of the network (only with existing traffic). The Figure 7 (a) shows the distribution of the overall exposure levels "case A" with and without artificial downloading. The Figure 7 (b) gives the distribution of the overall cumulative exposure "case B" with and without artificial downloading.



(a) (b)

Figure 7 : Distribution of the overall exposure (a) and overall cumulative exposure (case B) with 5G solicitation computationally integrated and compared to the measurement without specific solicitation (only with existing traffic).

The comparison between the statistical parameters of case A and case B with and without downloading on the 3 500 MHz band are shown in Table 3.

	Number of measures	Average (V/m)	Median (V/m)	Standard deviation
Overall exposure case A without download	464	1.51	1.24	1.00
Overall exposure case A with download	464	1.74	1.53	1.12
Variation (V/m)		0.23	0.29	0.12
Overall cumulative exposure case B without download	464	1.33	1.13	0.89
Overall cumulative case B with download	464	1.58	1.38	1.03
Variation (V/m)		0.25	0.25	0.15

Table 3 :Comparison of field strength statistics of overall exposure with and without downloading at 464 sites operating on 3 500 MHz band.

The average increase observed between the global exposure without downloading a file (only with existing traffic) and the global exposure relative to the single download of the 1 GB file is 21% (0.23 V/m) for case A and 31% (0.25 V/m) for the cumulative level for case B, in accordance with the exposure indicator introduced by the ANFR.

4 Conclusion

This paper focused on the analysis of exposure evolution related to the deployment of 5G on the national territory. More than 5 000 measurements were part of a large exposure monitoring program on sites hosting 5G on the low frequency bands 700 MHz and 2 100 MHz already used for 3G and 4G networks as well as on the new 3 500 MHz band exclusively dedicated to 5G. This paper was dedicated to the results of measurements performed on sites deploying 5G in the 3 500 MHz band and carried out during the year 2021.

First, the analysis of the overall measurements allowed to observe a slight increase on 1 358 sites measured at 4 months and then 8 months intervals after they are operational in 5G. Then, a sampling was performed on the most exposed sites where the analysis of details measurements showed an increase of the average exposure on all the mobile telephony bands. It also showed that the 800 MHz and 900 MHz bands contribute the most to exposure, followed by the 700 MHz, 1 800 MHz, 2 600 MHz, 2 100 MHz and 3 500 MHz bands respectively for phase 2 and the 1 800 MHz, 700 MHz and 2 100 MHz bands respectively for phase 3 (the 3 500 MHz band was not designated as the main contributor in phase 3).

As 5G traffic is still low at this stage of deployment, additional measurements specific to 5G in the 3500 MHz band were performed in the presence of artificially generated traffic to solicit the 5G antenna, by downloading a 1 GB file using a 5G phone. The first results suggest an increase of about 30% on the overall exposure.

It is possible to conclude, that the increase in the overall level on the 5G 3 500 MHz sites is not a priori related to an increase in the field strength on this band, but to an increase in levels on all other frequency bands of mobile telephony reflecting an increase in traffic. It is important to remember that phase 3 of the campaign took place at the end of 2021 where an increase in traffic could be observed.

The measurement campaign continues in 2022 and 2023 and will assess exposure after 1 to 2 years of 5G deployment.

Acknowledgement

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