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RESEARCH ARTICLE

POPULATION EXPOSURE TO RADIATION EMITTED BY MOBILE NETWORKS IN ABIDJAN, CÔTE D'IVOIRE

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Abstract

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The mobile telephony relay antennas number is growing with a view to cover the national territory and meet the subscriber communication needs. In Côte d'Ivoire, this fact is currently raising the harmfulness issue of RF emissions produced by these installations on the general public. This situation has forced the national frequency management body to conduct annual measurement campaigns to control the RF emission levels comparatively to the limit values recommended by international bodies. The current campaign in the city of Abidjan with ten municipalities, therefore, falls within this process framework and has made it possible to generally conclude that the recommended limit values are respected at all the different measurement points. However, these results specifically show high levels of radiation produced by mobile network installations compared to those from TV and FM network installations.

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Introduction:-

The use of devices and technologies that operate through electromagnetic fields (EMF) to transmit information is steadily increasing in Côte d'Ivoire. In addition to radio and television broadcasting, present for several decades, new technologies are now appearing: cordless telephones, WiFi routers, Bluetooth systems, etc. In particular, cell phone use is more and more common; according to the International Telecommunications Union (ITU), at the end of 2011, there were already more than 6 billion subscriptions to cell phone services worldwide [1]. Likewise, the Telecommunications Regulatory Authority in Côte d'Ivoire (ARTCI) believes that 85% of Ivorian households have access to a mobile phone in 2019, this percentage representing more than 37 million subscribers [2]. The needs in terms of telecommunication services in order to satisfy this large population are growing more and more. Populations who previously limited themselves to voice service have become familiar with the various services offered by mobile telephone networks with the service cost restructuring. This boom has forced operators to align themselves with the important needs of the populations. Then, it becomes obvious that the populations' satisfaction requires the radio equipments deployment in order to support these important needs. This has notably led to the relay antennas proliferation throughout the country, mainly in the city of Abidjan. However, the relay antenna multiplication in the cities, near to homes, causes many concerns among the populations for this cohabitation. We are therefore assisting recurring complaints from these populations related to the proximity of these relay stations to their residence places, thus fearing for their health.

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Indeed, the increasing exposure to radiofrequencies and the public concerns at the global level, have led health organizations such as the World Health Organization (WHO) to undertake large-scale research programs in order to respond to the concerns expressed. Through the International Committee for Non Ionizing Radiation Protection (ICNIRP), research has resulted in certain reference limits establishment that will allow public health preservation against RF emissions. In view of this situation in Côte d'Ivoire, the Ivorian Frequency Management Agency (AIGF) has been initiating annual non-ionizing radiation measurement campaigns for several years in order to verify compliance with the established reference limits. The main objective of these measurement campaigns is to force operators to respect these reference limits and to reassure the populations.

Through this paper, we will present in detail the non-ionizing radiation measurement campaign in Abidjan, carried out at the beginning of 2020. Then, we will analyze the results obtained during this campaign. For the rest, the paper is organized around six main sections. In fact, section 2 sets out the EMF harmfulness problematic, while section 3 addresses the normative and mathematical bases relatively to the non-ionizing radiation measurements. Section 4 focuses the data collection process and section 5 presents the results obtained from the measurement campaign and the underlying discussions. Finally, the paper ends with a conclusion in section 6.

EMF harmfulness problematic:-

We strongly note that mobile telephony relay antennas arouse much more fear among the population than FM or TV transmitters that exist for more than forty years. Such a difference in behavior can certainly be perceived as irrational because the often-cited difference in frequencies is not a relevant argument. Indeed, the frequency band “best absorbed” by the human body is that between 10 and 400 MHz [3]. Above 400 MHz, the radiation penetrates less deeply, most of the energy being absorbed by the superficial tissues (skin, fat, brain cavity or skull). This is why the standards are the most restrictive between 10 and 400 MHz. Consequently, for the same incident power density, the internal organs (brain, heart, liver, etc.) are irradiated less at 900 MHz than they are, for example, at 100 MHz. Finally, let us recall that the top of the frequency band allocated to television transmitters (840 MHz) is very close to GSM 900 bottom frequency. Another argument often put forward concerns the pulsed nature of the waves emitted by mobile telephony relay antennas because of the fact that these signals amplitude is modulated in very low frequency (at 0.16 ; 4.2 ; 216.7 and 1733.1 Hz). This is a hypothesis which, to our knowledge, has not been proven. In fact, for biological tissues to be sensitive to low frequency modulations, they would have to behave nonlinearly, which does not appear to be the case at frequencies used in mobile telephony [3]. In addition, it should be noted that the field radiated by a television transmitter must also be considered pulsed due to the pictures, fields and lines synchronization pulses whose periodicity is respectively 25.500 and 15.625 Hz. In this context, it is clear that the question about the human body exposure to EMF is not new. To this end, many works have been achieved and exist nowdays in the scientific literature ; some of these works are discussed in [4 - 9].

From the foregoing, it should be noted that faced with this very large sources number and their growing nature place in our modern society in recent years, the scientific community has looked into the EMF harmfulness issue, in particular, for those from artificial sources such as previously mentioned. Indeed, the questions that come up repeatedly are about technical and biological nature: what is the exposure level that produces adverse health effects and at what level populations are exposed ? For the first question, it is obvious that it has not yet received a definitive answer. However, for the second one, it is possible to give clear and irrefutable answers, since it is possible to do an in situ verification. It is therefore this second question that will be mainly addressed as part of this measurement campaign in Abidjan. This will give a clear idea of the relay antennas radiations mapping for the city's mobile telephone networks. This campaign results will contribute to a comparative analysis of EMF levels radiated by mobile telephone network relay antennas with those of TV and FM broadcasting relay antennas.

The emission sources generally produce radiation in predefined frequency bands. Mobile telephony sites (GSM, UMTS, LTE), local radio networks (WiFi, WiMax), radio broadcasting (TV, FM) can be seen in our environment but are not always known to the general public in terms of frequency and band. Here, we sum up in Table 1, the national territory coverage rate in mobile networks for the three operators which are ORANGE Côte d’Ivoire (OCI), MTN and MOOV. These different rates were obtained through the operators’ declarations.

Table 1:- National operators' mobile network coverage rate [2].

Services	OCI	MTN	MOOV
2G network	83.35 %	81.48 %	67.56 %

3G network	81.96 %	62.40 %	02.77 %
4G network	22.21 %	06.01 %	03.40 %

Normative and mathematical bases:-
This study was carried out on the basis of international normative references applicable to data collection missions within the framework of non-ionizing radiation measurements. The CENELEC standard (EN 50492, EN 50492-A1) [10] is one of the normative references adopted during this measurement campaign. This standard forms the basis for EMF measurement on site, in relation to the human body exposure in the vicinity of the base stations. In this case, it refers to several other standards including standard EN 50383 [11] relating to the measuring equipment calibration. We also refer here to the ICNIRP guidelines, relating to exposure limit values for the public and workers [12]. In general, the measurement points should be chosen to represent the highest exposure levels to which a person could be subjected in accordance with the neighboring antennas positions. These locations can be found either by quick verification using measurement equipment or, if this is not successful, by a calculation based on the theoretical propagation of neighboring antennas. The measurement should be made for a single point, 1.5 m above ground level. If the measurement result reaches the decision level, a spatial average of three points corresponding to the human body dimensions should be performed in order to determine the spatial average value, as shown in Figure 1.

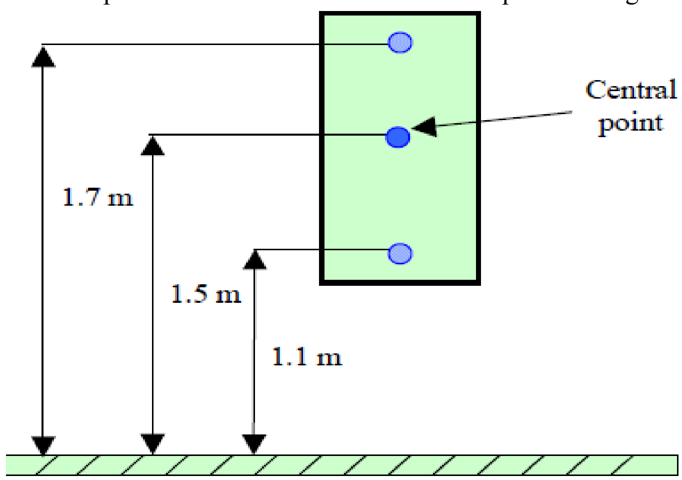

Figure 1:- Scanning to determine the spatial average for human body vertical extent.

Then, the measurements at each of the three points located on the vertical line that represent the human body vertical extent, must be recorded over a period of six minutes. Using the evaluated time average for each of the three points, the spatial average is calculated for that specific location by taking into account the average for the three points. For convenience, it is suggested to place the probe on a non-metallic tripod when taking detailed measurements for the time and spatial averages. According to [12], the spatial average is calculated using field strength measurements as follows:

$$E_{MoySpatial} = \sqrt{\frac{\sum_{i=1}^{3}\left(E_{moyRMS}\right)_i^2}{3}} \quad (1)$$

In this equation, $E_{MoySpatial}$ denotes the field strength spatial average for a given frequency and $\left(E_{moyRMS}\right)_i$ is the field strength temporal mean RMS value for the given frequency at the vertical line point i. Equation 1 can be used for measurements made in near-field and far-field regions.

It is also important to specify that the power radiated by a mobile station antenna depends on the communications number in progress in the cell. This number is relatively low during off-peak periods and almost zero at night. Indeed, extrapolation consists of evaluating the EMF amplitude at maximum power in the mobile network cases. Extrapolation is only required if the broadband measurement result is greater than 6 V/m or in special request cases. Whatever the technology, the principle is to measure signaling signals which are emitted at constant power and which allows access to the maximum power by calculation using network technical characteristics. Instantaneous pilot channel measurement (BCCH) is used for 2G (GSM), and in 3G (UMTS) case, instantaneous measurement of base station common pilot channel (CPICH) is used. And, for 4G (LTE), RS reference signal and S-SYNC synchroniwation signal are used. The extrapolated EMF denotes the value during maximum traffic. In [10], the extrapolations were evaluated according to the following formulas:

$$\begin{cases} E_{Max} = E_{BCCH} \times \sqrt{n_{TRX}} & for \quad GSM \\ E_{Max} = E_{CPICH} \times \sqrt{\eta_{CPICH}} & for \quad UMTS (2) \\ E_{Max} = E_{PBCH} \times \sqrt{n_{RS}} & for \quad LTE \end{cases}$$

In equation 2, n_{TRX} denotes, for GSM, the relevant ratio between the base station maximum power and the power allocated to the pilot channel, generally this is the relevant number of transmitters. η_{CPICH} represents for UMTS, the relevant ratio between the maximum allocated power and the power allocated to the pilot channel. The parameter n_{RS} designates for LTE, the ratio of the base station maximum total output power to the base station power of the reference signal RS, corresponding to the sub-carriers numbers. This parameter is provided by the operator or can be calculated theoretically by assuming that the RS sub-carriers are at the same power level as the other sub-carriers.In addition, probes must be chosen to cover the emissions of interest, in some cases two or more probes are needed to study the band of interest. In this case, the cumulative electric fields will be calculated using the values given by each device (treated as if they had been obtained individually) using the quadratic sum of the following formula:

$$E = \sqrt{\sum_{i=1}^{n} E_i^2} \ (3)$$

In this equation, n is the probes number covering the studied frequency band and the E_i are the values obtained individually by each equipment. The obtained value is always overestimated because sometimes the probe frequency bands overlap and the formula does not correct this.

It is also important to include the measurement equipments uncertainty for each measurement before determining compliance with the reference limits. Indeed, the uncertainties associated with the measurement equipment are mainly attributable to the equipments design. They can also be caused by other factors such as environmental conditions, temperature, humidity, etc. The measurement uncertainty must be evaluated taking into account a certain number of quantities. The standard uncertainty $U_{(x_i)}$ and the sensitivity coefficient C_i must be evaluated for the estimate x_i of each quantity. The combined standard uncertainty $U_c(y)$ of the estimate y is calculated as a weighted root sum square:

$$U_c(y) = \sqrt{\sum_{i=1}^{n} \left(C_i \times U_{(x_i)}\right)^2} \ (4)$$

The expanded measurement uncertainty U_e shall be indicated and is calculated as follows:

$$U_e = 1.96 \times U_c (5)$$

For most measurement results, the coverage factor of 1.96 gives a 95% confidence level for the near-normal distribution typical.

Data collection processe:-

This section focuses on the brief description of the measurement protocol used in this campaign context. This protocol aims mainly to realize in situ verification for fixed equipments used in telecommunications / ICT networks or for radio installations. The verification is carried out in accordance with the reference levels for public exposure to EMF. This is particularly the case here with mobile networks, which are the subject of great concern among populations abouttheir relay antennas growing number.

Measurement equipments:

The equipments which were used to perform the measurements are shown in Figure 2. These are the equipments for broadband measurements (Figure 2-a) and the equipments for selective or detailed measurements (Figure 2-b). The broadband measurement equipment is the Broadband Meter NBM 550_Probe. This equipment is made up of isotropic probes to pick up signals according to the frequency band used by the transmitter. Indeed, the measurements were carried out with an isotropic probe covering a band from 100 kHz to 6 GHz.For the detailed measurements, we used measurement chain made up of a probe to capture the signals, a spectrum analyzer to process the data received, a laptop which will be used to collect the measurements and make the post processings, a switch that allows the laptop and the spectrum analyzer to communicate, cables to connect the different equipments, and a dongle key that allows the processing software to run. Figure 2 shows the differents broadband and detailed measurmentequipmentcomponents. And, Table 2 lists these different components with their designations and references.

(a) **(b)**

Figure 2:- Broadband and detailed measurement devices.

Table 2:- List of measurement equipment components.

N°	DESCRIPTION	REFERENCE
01	Broadband meter device NBM 550_Probe (100 KHz à 6GHz)	2401/1B_D-0279 ET 2402/14B_D-0024
02	Isotropic probe SATIMO 100 KHz to 3 GHz	TAS_4511_05
03	Isotropic probe SATIMO 700 MHz to 6 GHZ	TSEMF26_4712_01 ET 4712_01
04	RF cable	CAB _4312_07 ET 4312_09
05	RF Switch box	SBOX _4312_05 ET 4312_04
06	PC (Software INSITE FREE) + Dongle	INSITE FREE V3.1
07	Spectrum analyzer	ANRITSU MS 2713E
08	Track mobile NOKIA	SAMSUNG NOTE 4
09	GPS positioner	GARMIN
10	Digital camera	SAMSUNG
11	Hygrometer	WBT- WEB POINT
12	Rangefinder	BUSHNELL
13	Compass	BUSHNELL

Measurement point analysis:

A measurement zone may in particular correspond to a dwelling, anopen place and accessible to public (public garden, etc.), or even an establishment open to public (shopping center, educational establishment, etc.). It can be reasonably extended as long as access is possible, for all places considered during the measurement. Once the measurement zone has been found, it will be necessary within this zone, to define the measurement site or point, as in the example of Figure 3. When characterizing a measurement point, it is not mandatory to find the location with the strongest signal. However, at the location chosen, the signal should be strong enough to determine if the signal variation is significant. If the RF emission levels at the point are low, it can be difficult to quantify the signal variation. In such a case, we assume that the field is stable and perform the detailed measurements for information on the site. Nevertheless, the measurementmain purpose is to determine whether there are any publicly accessible locations where the RF emission levels are equal to or greater than the limits applicable to uncontrolled environments, including the measurement uncertainty, in order to apply mitigation measures where appropriate.

Figure 3:- 4Example of Plateau City Hall measurement point area.

There are five measurement points in each of the ten municipalities of Abidjan (Abobo, Adjamé, Attécoubé, Cocody, Koumassi, Marcory, Plateau, Port-Bouët, Treichville and Yopougon); ie a total of fifty (50) measurement points showed in Figure 4. All these fifty measurement points chosen within the framework of this measurement campaign are generally large population concentration places and surrounded by several mobile network relay antennas.

Figure 4:- Synoptic view of all the 50 campaign measurement points.

The data collection process begins with site analysis and is carried out in accordance with standard NF EN 50492 (RF sources to be taken into consideration). The first step in the measurement process is to establish a topology of the transmitters that are around the measurement point and their "privileged" radiation directions. This topology will be done visually, by searches in databases, or by selective spectral measurements. The measurement site being clearly characterized, the measurement process can be initialized after determining the maximum field amplitude point using the operating mode recommended by appendix C.2.3 of standard NF EN 50492.

Measurement process:
The measurement should systematically cover all RF emissions from 100 kHz to 6 GHz. Roughly speaking, the first step is to choose between a broadband (Case A) or detailed frequency (Case B) global exposure measurement. Case A provides a result covering all sources and frequencies above 100 kHz. Case B provides a field values set for sources, frequencies or sub-bands. Indeed, the detailed exposure assessment is an investigation for each contribution from RF sources using frequency selective analysis.

As part of this measurement campaign, we systematically adopted Case B preceded by a broadband measurement (Case A). In principle, depending on the result obtained, the overall assessment is followed, where appropriate, by a detailed exposure assessment (Case B). Indeed, if the broadband measurement result is less than 6 V/m, the report must conclude that the reference levels are respected. In the case where the broadband measurement result is greater than or equal to 6 V/m, there is no possible conclusion at this stage and the process must be continued with a detailed evaluation (Case B) with extrapolation to transmitters maximum power. However, as previously indicated, AIGF has adopted as a general principle to perform the detailed measurement regardless of the value recorded during the broadband measurement. The measurements were all performed for a reference period of six minutes. In addition, we specify that we have a total of twenty one frequency bands selected by AIGF and which are been inspected during this campaign. The Table 3 shows these bands, the related services and the exposure limit values.

Table 3:- Bands, services and exposure limit value.

Frequency Bands (MHz)	Services	Exposure limit value (V/m)
0.1 – 10	Radio Broadcasting, PMR	87
10 – 30	PMR	28
30 – 87.5	PMR, Armed Forces, Radio amateurs	28
87.5 – 108	FM radio	28
108 – 174	Civil aviation, PMR	28
175-230	TV Band IV and V	28
230 – 470	Fixed system	28
470 – 694	Radio Broadcasting	28
694 – 790	Mobile Telephony 700	28
790 – 862	Mobile Telephony 800	36.22
925 – 960	Mobile Telephony 900	41.82
960 – 1710	Radionavigation, Aeronautics	42.6
1805 – 1880	Mobile Telephony 1800	51.45
1880 – 1920	DECT	59.62
2110 – 2170	UMTS (DL)	61
2300 – 2400	LTE TDD	61
2400 – 2483.5	Wifi	61
2500 – 2700	LTE 2600	61
2700 – 3400	Aeronautical radionavigation, Fixed, Mobile	61
3400 – 4200	Local Radio Loop, WiMax, Fixed satellite	61
4200 – 6000	Fixed, Mobile	61

In accordance with standard NF EN 50492, it is also important to note that the minimum distance between the end of the measurement probe and the operator, as well as any reflecting object, of 1 m for measurements between 100 kHz and 300 MHz and 0.5 m for measurements above 300 MHz, was strictly observed when performing the measurements.

Results and Discussions:-
This section purpose is to present the in situ measurement interpreted results carried out according to the protocol adopted by AIGF relating to the exposure limit values for public. EMF measurement results are only valid for the specified location and the measurement date. Indeed, the measurements for Cases A and B cover the 100 kHz – 6 GHz band. But, in view of the question specificity which motivated this study, we will present here the results of the global and detailed measurements only for the frequency bands affected mainly to mobile telephony.

Broadband measurement results:

The exposure overall level is the measurement results of EMFs radiatedglobally by all the transmitters surrounding the measurement point, visible or not. Table 4 shows the measurement results carried out on all the fifty different measurement points. This table also lists the measurement results at different heights relatively to Figure 1.

Table 4:- Broadband measurement exposure values for all the 50 measurement points.

Municipalities	Measurement point	Code	GPS coordinates		Electric fields (V/m)			Spatial average (V/m)
			Latitude (N)	Longitude (W)	1,1m	1,5m	1,7m	
ABOBO	Rond SAMAKE	01	5.4154	4.0064	0.97	1.12	1.16	1.08
	Carrefour N'Dotré	02	5.4432	4.0690	3.53	3.38	2.89	3,26
	Hôpital Général	03	5.4236	4.0160	3.23	3.29	2.90	3.14
	OLAM	04	5.4565	4.0536	1.85	1.94	1.62	1,80
	Poulet show	05	5.0119	4.0219	1.77	2.16	2.07	2.00
ADJAME	Grande Mosquée	06	5.3537	4.0266	5.60	3.81	4.65	4.68
	Marie Thérèse	07	5.3471	4.0198	1.69	2.15	2.52	2.12
	BAD Willy	08	5.3705	4.0253	1.11	1.53	1.98	1.54
	ST Michel	09	5.3448	4.0219	1.70	2.16	2.09	1.98
	ONG centre social	10	5.3581	4.0296	2.00	2.90	2.92	2.60
ATTECOUBE	Centre de santé urb	11	5.3156	4.0361	2.27	2.32	1.97	2.18
	Eglise méthodiste	12	5.3464	4.0337	1.10	1.31	1.48	1.29
	EPP GBEBOUTO	13	5.3458	4.0323	3.01	3.06	3.91	3.32
	PAROISSE	14	5.3499	4.0344	3.31	2.88	3.34	3.17
	Phcie Attecoube	15	5.3505	4.0321	1.82	2.07	2.22	2.03
COCODY	Angré COCOVICO	16	5.4031	3.9777	1.88	1.68	1.66	1.74
	ENA	17	5.3601	3.9975	2.41	2.31	2.22	2.31
	Mosquée golf	18	5.3385	3.9781	1.88	1.68	2.39	1.98
	Rond-point Palm.	19	5.3639	3.9597	2.00	2.32	1.98	2.10
	TERMINUS 81-82	20	5.4037	3.9857	2.94	2.99	3.60	3.17
Quartier Divo	Gd carrefour	21	5.2885	3.9712	2.89	3.05	3.08	3.00
	KAHIRA	22	5.2967	3.9689	3.01	3.27	3.07	3.11
	Cité Hallama	23	5.2795	3.9683	1.56	1.67	2.27	1.83
	Quartier Divo	24	5.3023	3.9531	1.71	2.04	1.87	1.87
	Ecole Source	25	5.3032	3.9473	2.30	2.54	2.53	2.45
MARCORY	AGEFOP	26	5.2843	3.9839	3.04	3.14	3.06	3.08
	CAP SUD	27	5.2975	3.9856	2.85	2.78	2.70	2.77
	Cité grand Moulin	28	5.2766	3.9922	1.13	1.46	1.85	1.48
	INJS	29	5.3085	3.9841	1.58	1.55	1.42	1.51
	Carrefour poubelle	30	5.2986	3.9915	1.87	2.19	2.66	2.24
PLATEAU	Hôtel de ville	31	5.3218	4.0196	5.58	5.00	4.87	5.15
	Pyramide	32	5.3217	4.0166	4.01	3.25	3.97	3.74
	Sorbonne	33	5.3250	4.0206	1.80	2.27	1.97	2.01
	Cathédrale	34	5.3330	4.0215	1.21	1.29	1.34	1.28
	Résidence ATTA	35	5.3269	4.0185	3.15	3.13	2.96	3.08
PORT-BOUET	ABATTOIR	36	5.2593	2.9021	1.42	1.50	1.54	1.48
	Akwaba	27	5.2677	2.8601	1.76	1.48	1.53	4.77
	Gonzague ST CYR	38	5.2421	2.6641	1.61	1.50	2.11	1.74
	Aéroport FHB	39	5.2548	2.7661	1.86	2.28	2.67	2.27
	VRIDI Cité	40	5.2639	2.9524	1.56	1.90	1.95	1.80
TREICHVILLE	Canal aux bois	41	5.3017	3.9943	4.89	4.36	4.43	4.56
	Cité du port	42	5.2883	3.0078	1.89	2.95	2.50	2.44
	Comafrique	43	5.2766	3.0089	2.78	2.75	2.04	2.52
	Jardin BIAFRA	44	5.3125	3.0065	2.72	3.12	3.00	2.94
	Rond-point rue 12	45	5.3068	3.0122	2.40	2.17	2.77	2.44

YOPOUGON	Koweït St.Shell	46	5.3220	4.0496	2.11	2.11	2.06	2.10
	LEM	47	5.3305	4.0758	2.36	2.54	2.50	2.46
	ST André	48	5.3409	4.0734	2.11	1.91	2.06	2.02
	KIMI	49	5.3417	4.0972	1.49	1.25	0.55	1.10
	Lycée jeunes filles	50	5.3456	4.0520	2.19	2.44	2.06	2.23

The values obtained on each site depend on the radioelectric activities of the environment in which the measurement point is bathed. The measurement spatial averages at the different points are also performed in the table for each point. The highest fields values are always lower than the decision limit value which is 6 V/m. This suggests that there is relatively low exposure to the public from radio installations.The uncertainty for Case A, i.e. the overall assessment covering frequencies from 100 kHz to 6 GHz, is provided in Table 5.

Table 5:- Uncertainty Case A - Global exposure assessment (100 kHz to 6 GHz).

Error source	Value max ± (dB)	Distribution	Sensitivity Coefficient	Reduction coefficient	Uncertainty standard 1σ ± (dB)
Connection	1.72	k=2	1	2	0.86
Frequency response	2.72	Rectangular	1	1.73	1.57
Linearity	0.46	Rectangular	1	1.73	0.27
Isotropy	0.15	Rectangular	1	1.73	0.09
Temperature	1	k=2	1	2	0.50
Spatial average	3	Rectangular	1	1.73	1.73
Human body influence	1	Rectangular	1	1.73	0.58
Derivative	1.19	Rectangular	1	1.73	0.69
Combined standard uncertainty U_c					2.70
Coverage factor k					1.96
Extended measurement uncertainty in dB : $U_e = 1.96 \times U_c$					**5.3**

Detailed measurement results:

Table 6 (the measurement points are designated by their codes) summarizes the results obtained for the selective measurements carried out in the mobile telephony services on the various points. This was done in order to reflect the study specificity which is to highlight the exposure levels comparatively to RF emissions produced by mobile telephone networks. The field levels obtained for these services are relatively low, and all the measured values were then extrapolated by calculation according to the formulas provided in equation 2.

Table 6:- Exposure detailed measurement values for all the 50 measurement points.

Code	GSM (925 – 960) MHz		UMTS (2110 – 2170) MHz		LTE 2600 (2500 – 2700) MHz	
	Measured	Extrapolated	Measured	Extrapolated	Measured	Extrapolated
01	1.1098	1.6187	0.2703	1.2090	0.3334	0.4946
02	4.6247	7.3262	0.3868	1.7298	0.0586	0.0869
03	0.0459	0.0717	0.6027	2.6953	2.1455	3.1828
04	0.2338	0.3209	0.1874	0.8379	0.1087	0.1613
05	1.0750	1.1636	0.0428	0.1914	0.3907	0.7698
06	1.0596	0.8619	0.2465	1.1022	0.0849	0.0925
07	0.8705	0.7482	1.3927	6.2285	0.7049	0.7680
08	2.8783	2.4409	0.2058	0.9206	0.2143	0.2335
09	0.2433	0.2252	0.0295	0.1319	0.0815	0.0888
10	1.5875	2.0316	0.7502	3.3549	0.3376	0.3678
11	0.7305	0.9315	0.3533	1.5799	0.5297	0.7970
12	0.0552	0.0762	0.0475	0.2123	0.0599	0.0901
13	0.2056	0.4001	0.0915	0.4091	0.1198	0.1803
14	0.3262	0.8057	0.0380	0.1697	0.2574	0.5319
15	0.1683	0.3980	0.3459	1.5467	0.0368	0.0553
16	0.4845	1.3616	0.2724	1.2183	1.1298	3.3581
17	2.9351	3.9606	0.6348	2.8390	5.4425	10.9556

18	0.0831	1.0610	0.0741	0.3312	0.2362	0.7021
19	1.3253	2.1090	0.0337	0.1508	0.2590	0.7725
20	0.0810	0.2681	0.1692	0.7566	0.2114	0.3179
21	0.2333	0.4684	0.4146	1.7725	0.3222	0.7681
22	2.6707	5.6411	0.4501	2.6548	0.0287	0.1100
23	0.0437	0.1378	0.0993	0.4254	0.2377	0.8182
24	0.1582	0.3187	0.2570	1.5279	0.3459	0.9884
25	3.0423	6.3092	1.4716	6.2998	0.1874	0.6501
26	2.6497	8.0175	1.5431	5.2061	0.0670	0.1648
27	2.9362	5.9482	0.5149	0.9989	0.0219	0.0797
28	0.7760	1.5794	0.4567	0.9396	0.0530	0.1451
29	0.4566	0.9889	1.3382	4.3739	0.0583	0.1446
30	2.1013	4.3218	1.7574	5.7439	0.0924	0.2458
31	5.5486	13.8859	2.2723	6.3055	0.0997	0.3119
32	0.1782	0.4942	1.8289	3.8926	0.2069	0.6426
33	0.6627	1.2186	1.0593	2.4253	0.1600	0.5632
34	0.4448	0.8079	0.6269	1.6634	0.1202	0.3936
35	0.4923	0.8892	2.4019	5.6302	0.0782	0.2469
36	0.7375	1.4820	0.7132	2.0631	0.0576	0.2028
37	0.8383	1.6850	0.7922	2.2684	0.0747	0.2669
38	0.0163	0.0494	0.5561	1.7072	0.6933	2.4325
39	0.0715	0.1515	4.1884	11.9435	0.0579	2.0250
40	0.2855	0.5774	0.0323	0.0704	0.6741	1.7006
41	1.4325	4.3055	3.3472	10.1148	0.1243	0.2477
42	1.8032	5.4623	2.0413	5.8376	0.9123	1.8114
43	0.9532	2.5021	0.9452	2.6952	0.7892	1.4403
44	1.1858	3.1376	1.3332	3.8087	0.0249	0.0512
45	0.5094	0.8552	7.5416	19.8568	0.1099	0.2181
46	4.2017	9.9366	0.9052	3.1884	0.1475	0.4404
47	2.3499	4.9080	1.4665	4.0791	0.0417	0.1758
48	0.1020	0.2452	2.3800	4.2424	0.3300	1.0297
49	2.0357	6.8329	0.0617	0.3026	0.1163	0.3444
50	0.0855	0.3268	0.1547	0.4307	0.1381	0.4420

We specify that these measurements were performed for each measurement point at the height which gave the highest electric field level during the broadband measurement. In this table 6, the field values obtained in the GSM 1800 and LTE 800 band have been knowingly ignored because they are very low compared to the others. In addition, we note that all the extrapolated values are significantly lower than the respective limit values of the different service bands, particularly for the bands dedicated to mobile telephony. However, we notice five extrapolated values that are relatively high compared to the others. These values are respectively 19.8568 V/m at the "Rond-point rue 12 (code 45)" and 10.1148 V/m at the "Canal aux bois (code 41)" measurement points for the UMTS band in Treichville; 11.9435 V/m at the "FHB Airport (code 39)" measurement point for the UMTS band in Port-Bouët; 13.8859 V/m at the " Hôtel de ville (code 31)" measurement point for the GSM 900 band in Plateau; and 10.9556 V/m obtained at the "ENA (code 17)" measurement point for the service band assigned to LTE 2600 in Cocody. As we can see, all these values considered high here are low compared to the respective reference limits of Table 4, even adding the value of the expanded measurement uncertainty. Indeed, the uncertainty relating to Case B, namely the detailed assessment covering frequencies from 100 kHz to 6 GHz, is provided in Table 7.

Table 7:- Uncertainty Case B - Detailed exposure assessment (100 kHz to 6 GHz).

Error source	**Value max ± (dB)**	**Distribution**	**Sensitivity Coefficient**	**Reduction coefficient**	**Uncertainty standard 1σ ± (dB)**
Connection	2.16	k=2	1	2	1.08
Derivative	2.42	Rectangular	1	1.73	1.40
Linearity	0.57	Rectangular	1	1.73	0.33

Frequency interpolation	2.25	Rectangular	1	1.73	1.30
Isotropy	0.58	k=2	1	1.73	0.33
Spatial average	3	Rectangular	1	1.73	1.73
Human body influence	1	Rectangular	1	1.73	0.58
Decoder	2	Rectangular	1	1.73	1.15
Combined standard uncertainty U_c					3.1
Coverage factor k					1.96
Extended measurement uncertainty in dB : $U_e = 1.96 \times U_c$					**6.1**

Discussions:-

Result discussions are the last step in our analysis process and are based on the data collected during the measurements. In fact, we recall that our study is not intended to highlight EMF effects on human body, especially since we do not have the expertise. However, it is clear that some professionals in the medical domain, ensure that EMFradiated by mobile phones and relay antennas are so complex in their dangers and their alteration mode depends on an organism or from one person to another. These EMF can therefore cause long and short term negative effects on any individual such as chronic fatigue, insomnia, to name but a few. In the same vein, we find that EMF radiated by mobile phone antennas are likely to produce increase temperature for human body beyond the norms. When human body is exposed to EMF, an increase in temperature is observed for relatively high intensities.

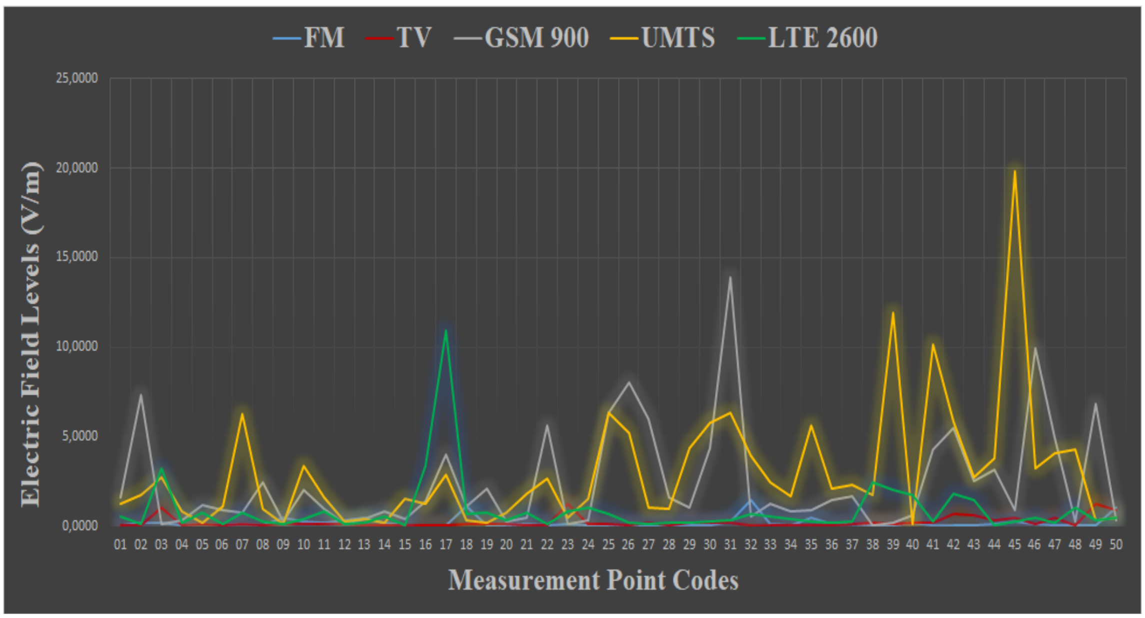

Figure 5:- Field level comparative curves for mobile telephony and TV-FM.

According some experts, the athermic effects result from a direct interaction with the tissues and have, among other things, an influence on the nervous system as previously mentioned. The athermic effects existence is therefore a very controversial issue. Some researchers, advocating the precautionary principle, want more restrictive exposure limit values to be adopted. Conversely, official bodies such as ICNIRP and WHO declare that there is, to date and in accordance with the studies already carried out, no reliable scientific basis that could justify exposure limit values reduction. This is the reason why our approach will be based only on the current exposure limits recommended by these authorities for public exposure in an uncontrolled environment.

Indeed, it is important to make a difference between relay antennas issue and that of mobile phones use. Although both fall within EMF domain impact, the exposure levels are very different. In addition, it is useful to remember that we are surrounded by different EMF frequencies (power lines, TV screens, radio broadcasting, telephones and internet, radars, etc). In our study case, we mainly focused on FM and TV RF emissions, to compare them to those of mobile telephony that only represent a small part of all EMF sources. Then, we can see in Figure 5, the comparative curves of mobile telephony relay antennas radiation levels to those of FM and TV relay station antennas. It clearly appears that in our case, the field levels radiated by FM and TV antennas (curves in blue and red in Figure 5) are relatively very low compared to mobile telephony antennas levels (curves in gray, orange, and green in the same figure). The field levels are all less than 1.2450 V/m for TV systems and 1.4702 V/m for FM systems, while in the case of mobile telephony we see peak values at 13.8859 V/m for GSM 900, 19.8568 V/m for UMTS and 10.9556 V/m for LTE 2600 systems. We opted for this comparison for the simple reason that FM and TV relay antennas had existed for a long time and populations were bathed in their radiations, but with the cell phone relay antennas deployment, there has been an outcry about their EMF harmfulness. With these results, we can understand the growing concern of the populations, even if these field levels remain below the recommended exposure limit values (41.82 V/m for GSM 900, and 61 V/m for UMTS and LTE 2600). It is therefore important to underline that because of their propagation in "umbrella effect", EMF radiated by the antennas gradually affect nearby organisms, and their high power at the antenna level, decreases rapidly with distance. Despite these realities, public is concerned about the possible existence of risks, which currently remains a mystery. For our part, all of the measurements carried out in this study concluded that the exposure limit values prescribed by ICNIRP were respected (see Table 3) and confirmed broadband measurement values obtained in Table 4.

Conclusion:-

AIGF manages RF emissions in Côte d'Ivoire but does not have a regulatory framework to sanction any limit level exceeding outside actors' interpellation. However, it does a lot of control by organizing annual campaigns to measure non-ionizing radiation. It is therefore within this framework that the current measurement campaign took place. Its objectives were to verify the compliance of exposure with recommanded values, to know the exposure by frequency for all frequencies, and to specifically know the details of the exposure caused by mobile telephony services which is currently the source concern among populations. To answer this, the measurements were carried out according to the measurement protocol Case B preceded by Case A. All the broadband measurements collected are below the decision value of 6 V/m, which did not, in reality, require extensive monitoring. In addition, according to the detailed measurements and analyzes presented in this paper, it is clear that the values obtained for mobile telephony do not a priori present a danger for the general public if we stick to the ICNIRP studies.

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