Academia Journal of Scientific Research 5(5): 103-114, May 2017
DOI: 10.15413/ajsr.2017.0304
ISSN: 2315-7712

Research Paper

Non-ionizing radiation and spectrum occupancy measurements

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Accepted 2nd May, 2017

ABSTRACT

The expansion in the use of wireless telecommunication systems and its associated rain of non-ionizing electromagnetic radiation motivates the study of these emissions and the impact on the population. There are national and international recommendations to verify compliance with the emission limits of electromagnetic radiation. The recommendations define the measurement set-up and ways to evaluate the results. This project aims to implement the measurement set-up and the use of radio frequency spectrum for non-ionizing radiation emissions at the frequency bands of mobile phone technologies following the measurement procedure defined in the standards.

Keywords: Measurements, frequency spectrum, power density, limit values.

INTRODUCTION

The constant progress of mobile and wireless telecommunication systems brings a greater concern on the effects of non-ionizing electromagnetic radiation on human health. On the other hand, with the great popularity of wireless systems, the radio spectrum has become a scarce resource in many countries. It motivates the development of novel spectrum access techniques to allow an efficient use of this resource.

These issues motivate the development of a measurement set-up to obtain a realistic set of measurements of power density and spectrum occupancy in the bands of mobile GSM-900 and GSM-1800 in order to know the current situation in our country.

These measurements will provide data which will then be processed and analyzed in order to determine and compare these measurements in relation to the CNC Resolution No. 3690 and the recommendations provided by the ITU. The measurement set-up was implemented in the downtown of Salta, Capital City, Argentina.

MATERIALS AND METHODS

The power density was measured by using two different measurement methods that employ two instruments in order to be able to validate the obtained results. To determine the spectral efficiency, a spectrum analyzer, as is depicted in (Figure 1) was employed.

Figure 1 shows the measurement set-up. The signal provided by the sensor is filtered and amplified before being converted to digital format. The digital data is transferred to the wireless module for onward transmission to the base station. At the base station, the information is processed and the results presented by using a graphical representation.

Amplifier

The amplifier block is constituted by an RF low noise amplifier (LNA) that operates in the range of 10 MHz to 6 GHz with a gain of 15 db.

Spectrum analyzer

The utilized spectrum analyzer is a portable analyzer Spectran HF 6065 v4, with a frequency range of 10 MHz to 6 GHz, an average noise level of -135 dBm (1 Hz) and a 1 ms sampling time. It consists of a directional antenna in

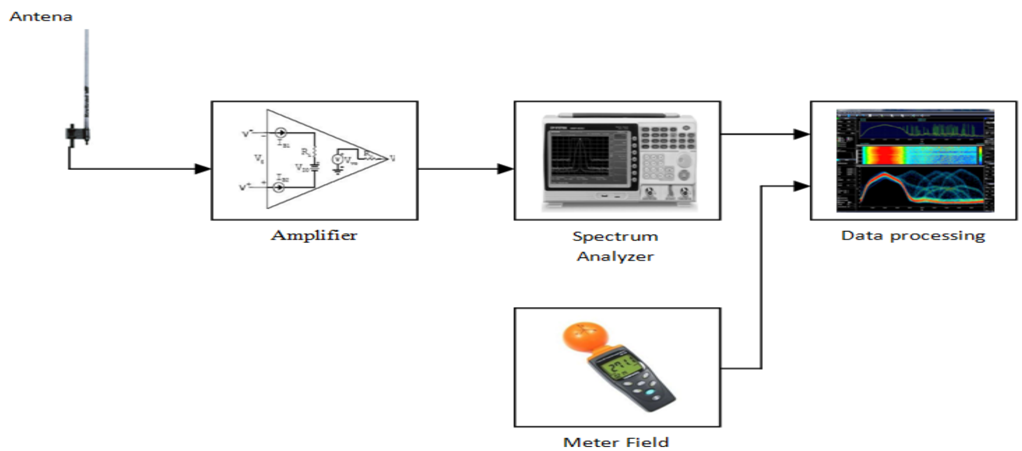

Figure 1: Measurement set-up.

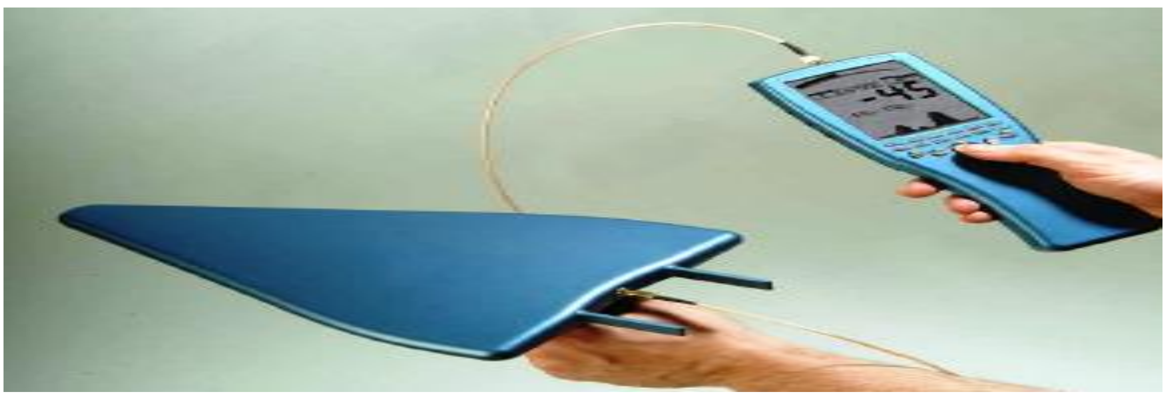

Figure 2: Spectrum analyzer.

Figure 3: Field meter.

the range of 700 MHz to 6 GHz and 5 dbi gain (Figure 2).

Field meter

The employed field meter is a TES-92, which is a tri-axial meter that operates in the range of 50 to 3.5 MHz, with a dynamic range of 75 dB. Due to the non-linearity of the sensor with the frequency correction factor to more 1 db a frequency range of 50 MHz to 1.9 GHz and 2.4 db for a frequency range of 1.9 to 3.5 GHz, respectively is used. The setting time of our instrument is 1 s for taking the measurement value of 0 to 90%. Figure 3 shows the equipment.

Figure 4: Antenna area N.

Figure 5: Antenna area N.

Power density

The demand for wireless technology has dramatically increased in recent years and leads an increase in the installation of antennas in densely populated areas in order to provide a good quality of service.

However, the placements of novel antennas need to be carefully studied with the purpose of fulfilling the current regulation in terms of protection of the population regarding the maximum permitted radiation.

Taking into account the current regulations on the subject (National Commission of Communications, 2004), the measurements of power density was performed using two independent instruments in order to verify the acquired measurements.

Measurement points

The measurement points were selected following the rules stipulated by the resolution 3690/2004 (CNC) (National Commission of Communications, 2004). The resolution defines the next steps:

a) Visual survey of the site;
b) At least 16 measuring points should be set. Four of which at least must be placed in the line of maximum spread of the antenna;
c) Measurements should be made in the rush hour;
d) In order to reduce the interference from secondary radiators, the probe need to be placed at least 20 cm away from the re-irradiation source;
e) The measurement of the electric and magnetic fields should be performed separately in the near-field region and the power density calculated.

The measuring points were established depending on where the antenna is placed. These points can be seen in Figures 4, 5 and 6.

Measurement techniques

Measurement methods for fixed installations such as transmitting antennas can be divided into:

- Continuous recording for long periods of time (years); - Continuous registration for shorter periods: it is

Figure 6: Antenna area NE.

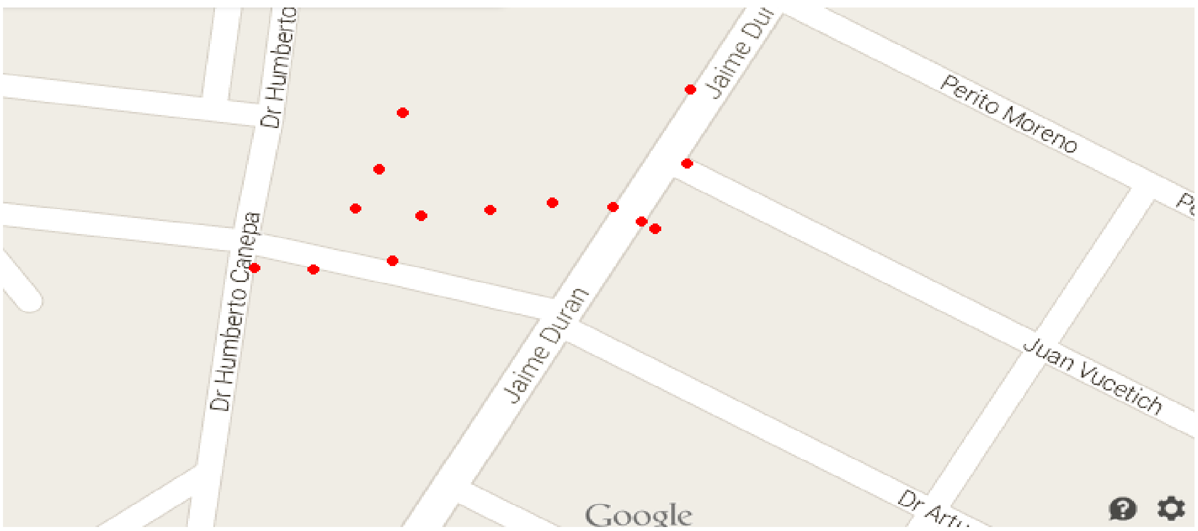

Figure 7: Antenna area N.

employed to study day and night variations and other short-term variations in the level of a signal;
- Sampling at close intervals (for example, every 2 s for 5 min);
- Sampling at long time intervals (for example, every 90 min for 10 min);
- Instantaneous measurements: The samples are obtained from the distribution of the field strength.

Once located at the required height, the antenna must be rotated in the direction of the transmitter. During the measurement period, the height and orientation of the antenna must be varied to obtain readings and records of the maximum field strength.
In the course of this research, the instantaneous measurements method was chosen. The other methods require large measurement time and the placement of the equipment in complicated scenarios due to the location of the antennas.
For the establishment of measuring points, the measurement of the near and far field was employed. These points are shown in Figures 7, 8 and 9.

Data logging

The data recording was made in technical format as recommended by the CNC Resolution No. 3690 (National Commission of Communications, 2004). It consists of the following items:

- Date of measurement;
- Start time;
- End time;

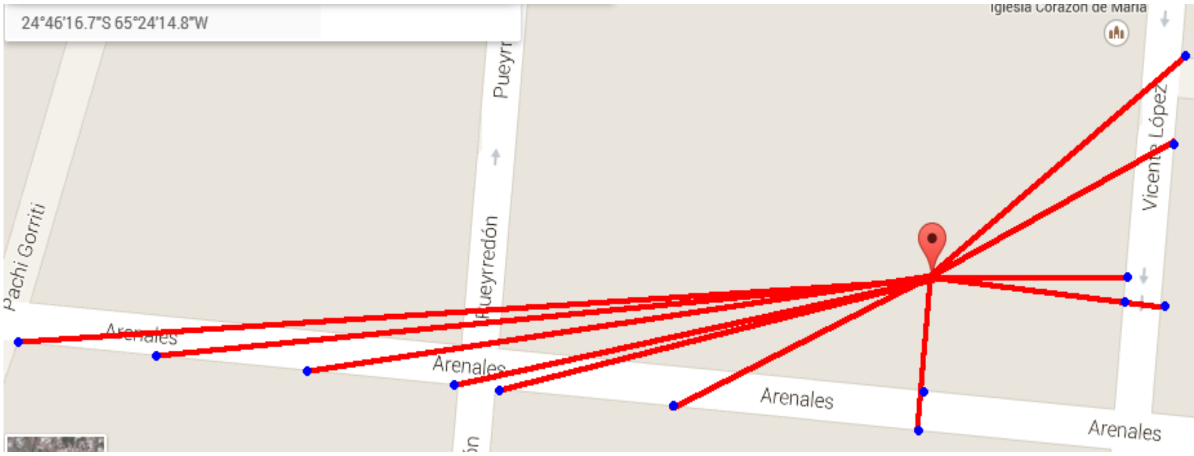

Figure 8: Antenna area N.

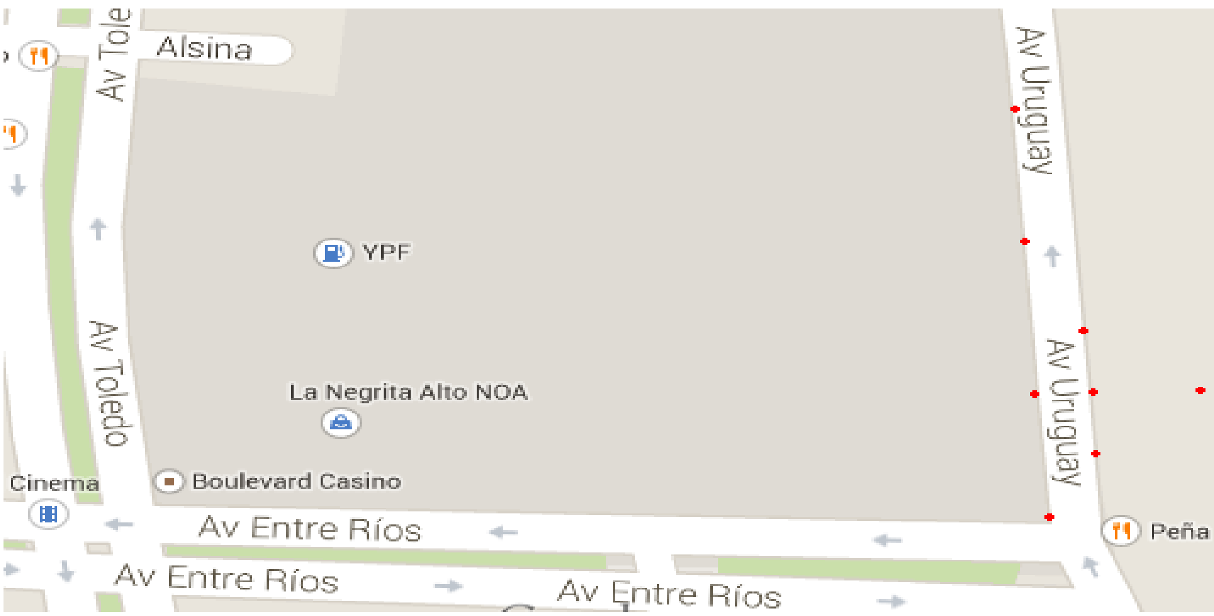

Figure 9: Antenna area NE.

- Sketch of the measurement points;
- Photos of antenna facilities;
- Table of measured values;
- Features of the employed instruments;
- Other relevant information.

Data processing

The collected information was organized in a table and compared with the maximum threshold values allowed by the resolution (National Commission of Communications, 2004) (Argentina) and the threshold values set by international standards (ANSI / IEEE de 1992) (Tables 1 and 2). The measured values are organized in a table as shown in Table 3. For displaying the data obtained it was decided that bar graphs be used (Figure 10).

SPECTRUM OCCUPANCY

Due to increased demand of spectrum by several telecommunication services, a congested radio frequency spectrum was found in large cities. This situation affected the performance of communication systems and damaged the quality of service (QoS) (Barnes, 2013). There are several spectrum measurement techniques which provide information on the extent of use of the different bands, allowing an efficient and smart management of the spectrum.

Table 1: Limit values CNC.

Frequency range f (Mhz)	Density of equivalent plane wave power (Mw/cm²)	Electric field E (v/m)	Magnetic field H (A/m)
0.3 - 1	20	275	0.73
1 - 10	20/f	275/f	0.73/f
10 - 400	0.2	27.5	0.073
400 - 2000	f/2000	1/(1375f)2	-
2000 - 100000	1	61.4	-

Table 2: Limit values ANSI/IEEE.

Frequencies (MHz)	ANSI /IEEE (mW/cm²)	Res.202/96 M.S.y.A.S. (mW/cm²)
850	0.57	0.45
1900	1.26	0.95

Table 3: Level of occupation.

Occupation (%)	Independent samples	Dependent samples	Sampling time (h)
6.67	5368	16641	18.5
10	3461	10730	12
15	2117	6563	7.3
20	1535	4759	5.3
30	849	2632	2,9
40	573	1777	2
50	381	1182	1.3
60	253	785	0.9
70	162	166	0.2

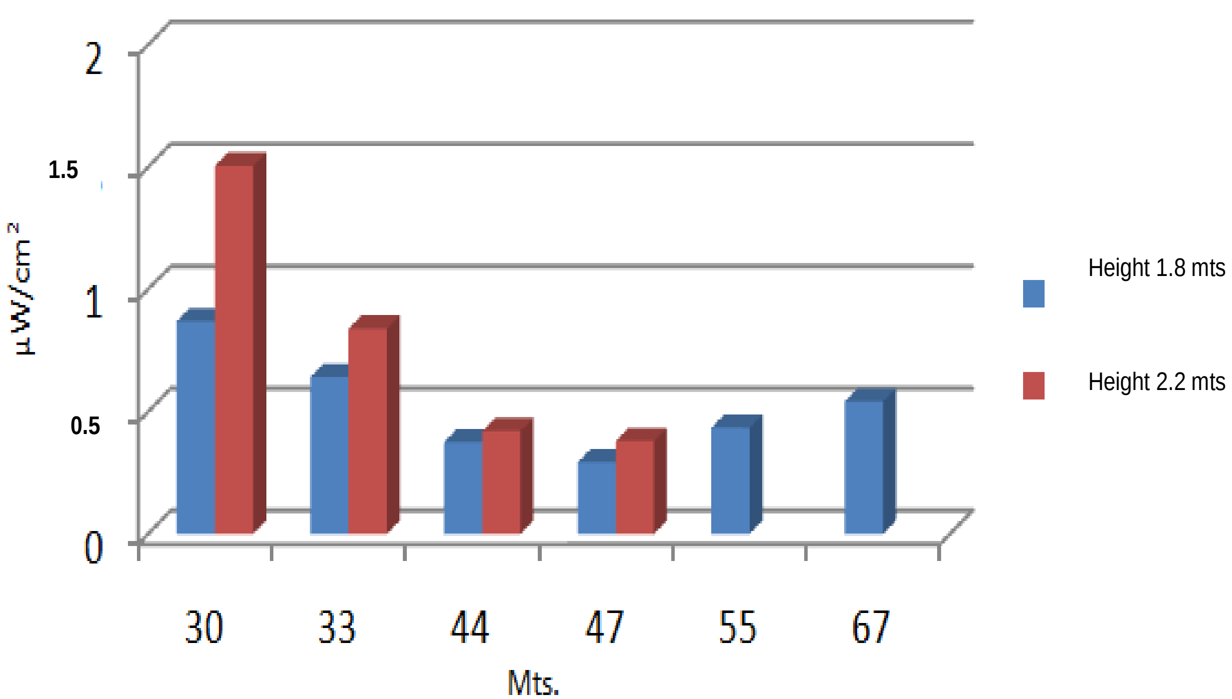

Figure 10: Submission of data.

Figure 11: Measurement points.

Figure 4. Values.

Distance to the antenna (Mts)	Power density (uW/cm²)	
	Height measurement (1.8 Mts)	Height measurement (2.2 Mts)
30	0.87	1.505
33	0.641	0.84
44	0.375	0.421
47	0.293	0.38
55	0.435	-
67	0.542	-

Data acquisition

In order to execute the data acquisition, it is necessary to define the following issues: a) measuring points and b) measurement techniques.

Measurement points

In order to select the measurement points, the recommendations from SM.1880, SM.182-5, SM.1599-1, manual spectrum monitoring ITU and CNC resolution 3690 were taken in account. They are summarized as:

- The points are in the far field situation;
- The decoupling due to its height is enough to avoid the influence of the ground during the measurements;
- Minor obstacles (buildings and trees etc) to prevent reflections and other effects due to multipath were considered;
- We assumed that the measurement place is free of strong electromagnetic fields from other sources;
- The points are far away from high intensity radio transmissions;
- The points are inside of the service area;
- They are not affected by noise from electrical devices (PC and motors etc).

Based on all these considerations and taking into account the availability of the university campus, a set of measurement points was established and are indicated by yellow markers in Figure 11.

Measurement techniques

The measurement instruments which consist of the antenna, spectrum analyzer and a PC to store data were placed at the measurement points previously defined. The duration of the measurement time is a combination of scanning all channels, typical values expected duration of radio transmissions, the number of channels to be scanned and the desired accuracy of the results.

To determine the time of data storage with a 95% confidence level Table 4 was taken into account (Geneva, 2011). Based on the number of samples and the occupancy level, measurement and storage intervals of 30 min, 1 and 2 h were considered.

The measuring method used is based on the measurement of the ratio of the FFT-based powers which requires little

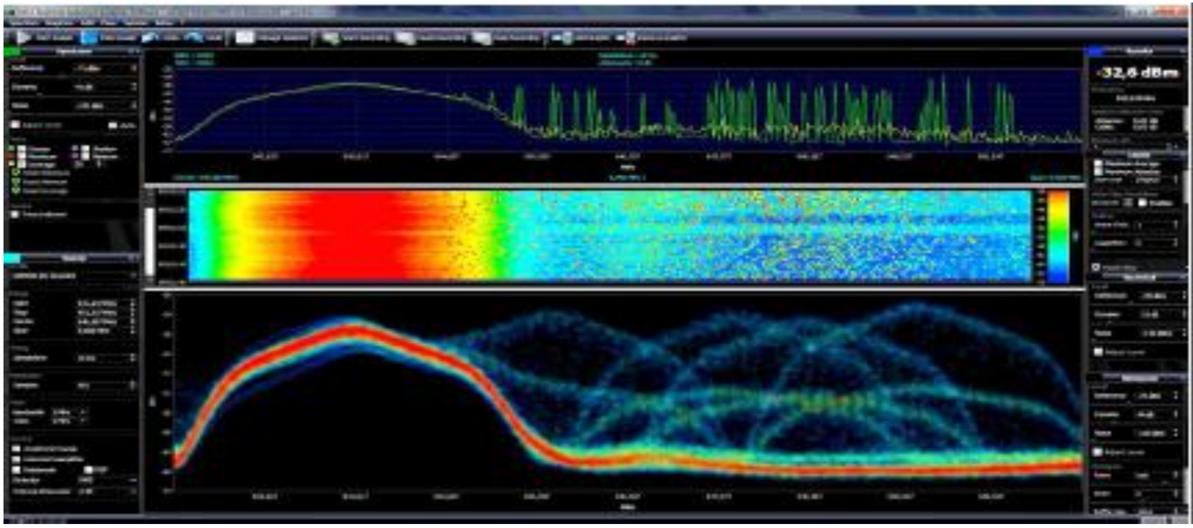

Figure 12: MCS spectrum analyzer.

or no knowledge about the detailed parameters of modulation. This method considers the part of the measured spectrum that stands out above the noise background.

Moreover, the power ratio method is much less sensitive to the chosen window. The signal to noise ratio can be increased when it is insufficient to determine the bandwidth that includes 99% power, using a longer integration with a higher resolution FFT.

To increase the measurements accuracy, it is recommended that:

a) Measurements should be made under optimum reception conditions to avoid the introduction of new variables due to fading or interference;
b) If possible, operators should not know the exact values to be measured, so that they are not tempted to manipulate the results;
c) The observation time per channel depends on the scanning speed of the monitoring equipment;
d) Provided that the above equation is applied to spectrum analyzers, when RBW is set to a value equal to the bandwidth of the channel, it can be considered that the number of channels is the number of sector 1 by scanning and observation time as dwell time per sector;
e) The instrument must be able to perform scans at an acceptable speed for detecting short transmissions.

Data logging

The MCS Spectrum Analyzer generates a record of the data which is stored in a file with MDR extension (Figure 12). This file can be converted to a spreadsheet type (Table 5). After obtaining a set of files in spreadsheet format, they can be evaluated to determine the occupancy rate per channel spectrum.

Data processing

The spectrum occupancy per channel can be obtained by using two different methods:

a) Capture all transmissions in the observed band;
b) Statistical method.

The first requires maximum scanning time for all channels and is half the minimum time of activation or deactivation of any transmission in the band, taking between whichever is lower. This method provides an accuracy which is independent of the occupation rate allowing a short evaluation period.

The second method is used especially when considering bursts of digital systems. In this case, the minimum transmission time may be too small for practical application for the aforementioned principle. However, if the technical verification time is long enough to provide sufficient number of samples, the result of the occupation will be correct because the statistical probability of capturing a transmission compared to the probability of losing is the same as the active cycle of the transmission itself.

In our work, in function of the employed instruments, the first method was selected and it consists of storing the signal strength of each frequency step. Through further processing, the percentage of time that the signal is above a certain threshold level is evaluated. In our analysis, a threshold of -70 dBm was considered as a free band and -40 dbm is defined as reception threshold. From these thresholds we proceeded to analyze each channel and determine the degree of occupation.

Table 5: Data in spreadsheet format.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Timestamp	Measure Unit	876000000	877500000	879000000	880500000	882000000	883500000	885000000	886500000	888000000	889500000	891000000	892500000	894000000
2	2015-04-22T14:48:39.970	dBm	-60.748	-70.420	-61.443	-61.522	-60.300	-58.753	-58.985	-60.668	-61.378	-61.052	-61.877	-56.155	-69.019
3	2015-04-22T14:48:41.686	dBm	-60.658	-68.574	-61.627	-60.523	-60.519	-58.335	-60.865	-62.565	-61.918	-62.786	-63.819	-56.089	-69.734
4	2015-04-22T14:48:43.480	dBm	-61.562	-70.545	-61.790	-61.988	-60.842	-58.402	-55.341	-61.689	-63.159	-61.266	-60.974	-55.906	-70.120
5	2015-04-22T14:48:45.040	dBm	-62.444	-72.737	-65.059	-63.614	-62.944	-61.581	-59.551	-61.839	-62.630	-63.173	-61.707	-55.870	-69.488
6	2015-04-22T14:48:46.584	dBm	-61.920	-70.462	-64.341	-62.817	-61.381	-59.428	-61.541	-62.557	-64.184	-64.370	-62.074	-55.419	-69.814
7	2015-04-22T14:48:48.129	dBm	-62.344	-69.189	-64.047	-61.995	-61.120	-60.412	-58.712	-61.375	-64.238	-62.645	-62.717	-55.511	-69.626
8	2015-04-22T14:48:49.673	dBm	-62.353	-71.325	-63.661	-62.225	-61.074	-59.420	-60.461	-62.802	-64.066	-62.404	-63.306	-55.795	-70.054
9	2015-04-22T14:48:51.373	dBm	-62.347	-70.614	-64.708	-63.706	-63.303	-61.099	-59.319	-63.000	-61.636	-62.540	-61.509	-56.013	-69.519
10	2015-04-22T14:48:53.058	dBm	-63.380	-72.590	-64.018	-64.091	-63.397	-60.580	-61.883	-62.515	-61.310	-63.974	-61.797	-55.962	-68.733
11	2015-04-22T14:48:54.868	dBm	-63.028	-71.135	-63.280	-63.486	-62.011	-60.942	-60.167	-66.600	-64.993	-66.061	-65.975	-58.299	-70.791
12	2015-04-22T14:48:56.444	dBm	-62.330	-71.454	-64.492	-64.121	-62.265	-61.075	-59.133	-62.183	-62.724	-62.429	-64.188	-56.507	-69.302
13	2015-04-22T14:48:58.472	dBm	-62.779	-70.629	-63.584	-63.590	-61.752	-61.257	-57.782	-60.753	-64.149	-63.925	-63.870	-55.637	-68.842
14	2015-04-22T14:49:00.282	dBm	-60.078	-70.922	-62.049	-60.476	-59.590	-59.577	-58.798	-60.696	-60.349	-62.210	-60.412	-55.655	-69.467
15	2015-04-22T14:49:01.951	dBm	-59.815	-69.446	-62.060	-59.762	-59.774	-57.548	-57.816	-64.351	-60.924	-60.826	-61.058	-55.951	-68.297
16	2015-04-22T14:49:03.511	dBm	-59.545	-69.706	-61.801	-61.519	-59.993	-58.675	-56.667	-60.033	-61.970	-60.717	-62.295	-55.827	-68.515
17	2015-04-22T14:49:05.196	dBm	-60.189	-68.578	-60.937	-61.234	-61.099	-59.690	-55.487	-59.479	-61.432	-61.777	-61.432	-55.511	-69.384
18	2015-04-22T14:49:06.881	dBm	-60.223	-70.632	-61.714	-61.212	-59.787	-57.914	-58.937	-62.106	-61.890	-61.109	-62.586	-55.654	-69.307
19	2015-04-22T14:49:08.706	dBm	-60.134	-71.340	-61.888	-60.008	-60.032	-58.264	-57.502	-63.856	-61.387	-60.853	-62.740	-55.672	-68.643
20	2015-04-22T14:49:10.625	dBm	-60.234	-67.256	-60.993	-60.816	-60.697	-58.204	-57.550	-60.090	-61.280	-60.180	-60.152	-55.648	-68.650
21	2015-04-22T14:49:12.325	dBm	-63.325	-70.801	-63.969	-64.222	-63.160	-62.197	-63.837	-60.181	-63.846	-62.577	-62.892	-56.250	-68.470
22	2015-04-22T14:49:13.994	dBm	-63.443	-73.214	-63.997	-64.935	-63.542	-62.198	-61.261	-60.097	-63.049	-64.092	-64.588	-55.781	-69.171

Data processing software

Data processing software was developed for the analysis of each measurement point, (Figure 13). This program analyzes data per channel, obtaining an occupancy rate according to the settled limit values. This spectrum analysis provides the value of the overall occupancy rate in selected measurement point (Figures 14 to 16) occupying the graphics obtained by channel measurement at different points in periods of 30 min. As can be seen in different parts of the spectrum measurement it is underemployed. To corroborate the trend graph average of all measurement points per channel was performed (Figure 17).

CONCLUSIONS

Although in all cases the levels of radiation do not exceed the limit values set by the resolution (National Commission of Communications, 2004) and the radiation values have a strong dependence on the environmental conditions at the measuring site. The presence of metallic elements of large dimensions such as metallic signage, tin

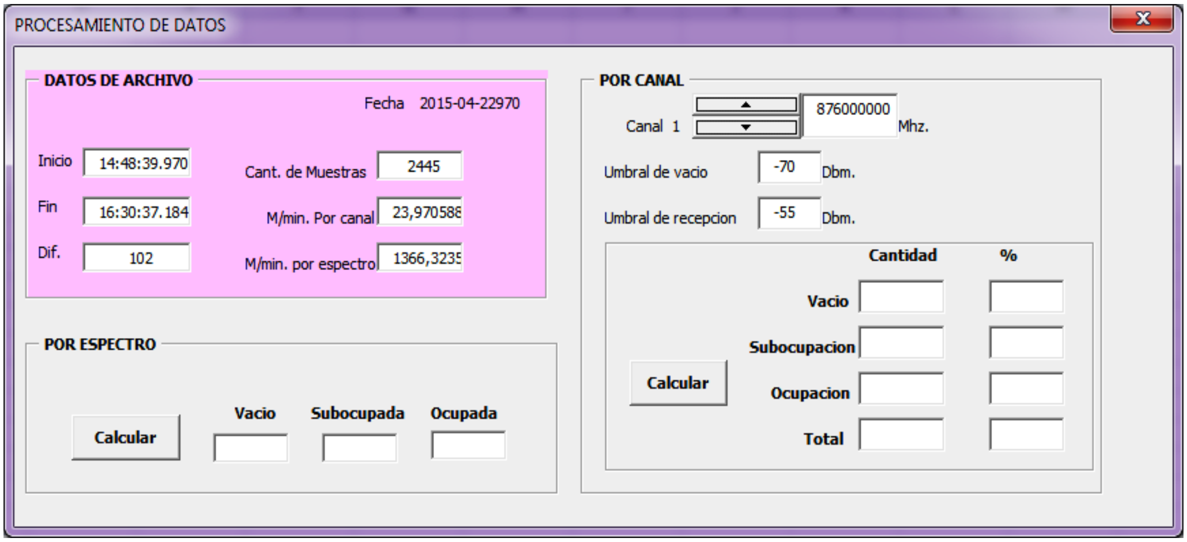

Figure 13: Program for data processing.

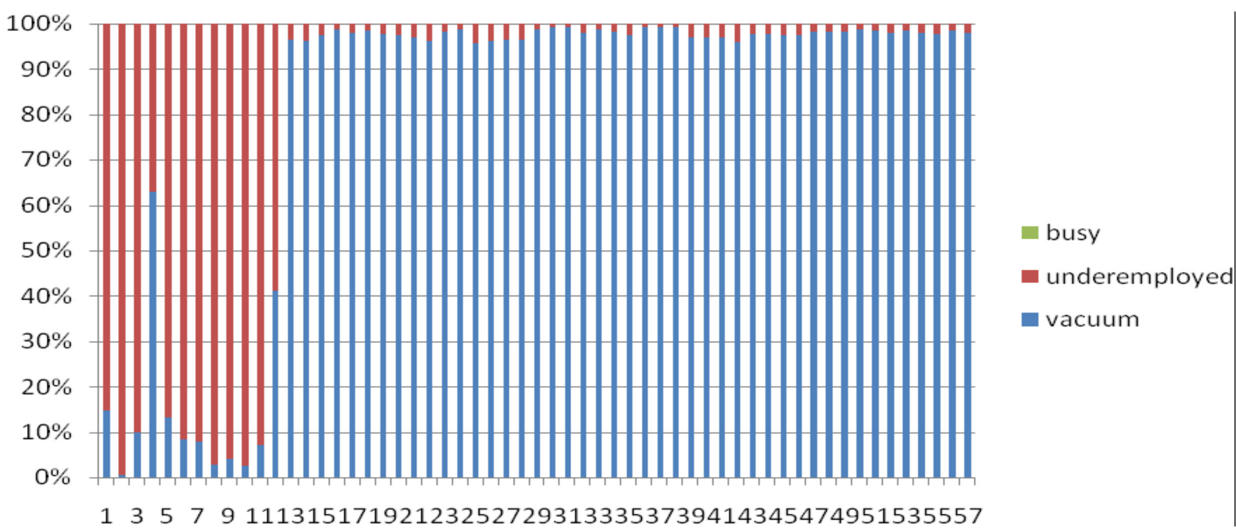

Figure 14: Measuring classroom 9.

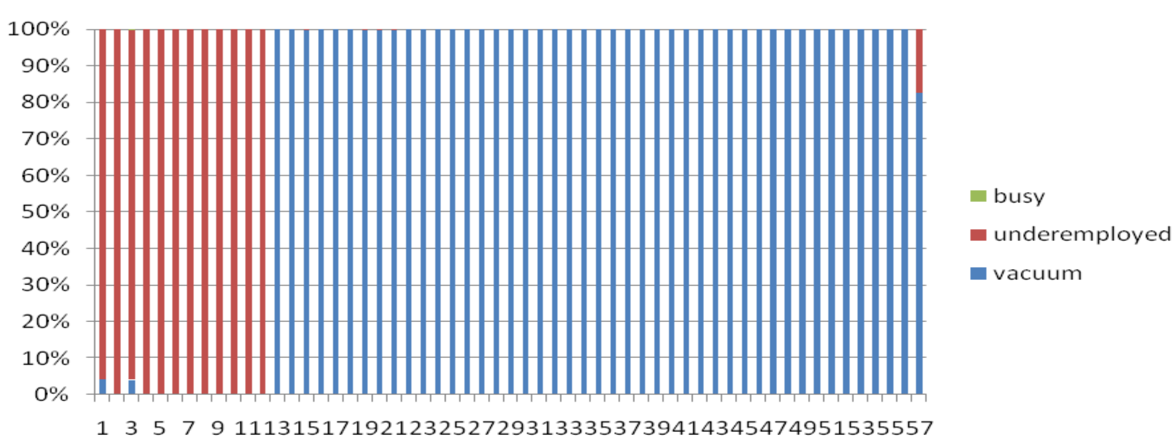

Figure 15: Measurement in court.

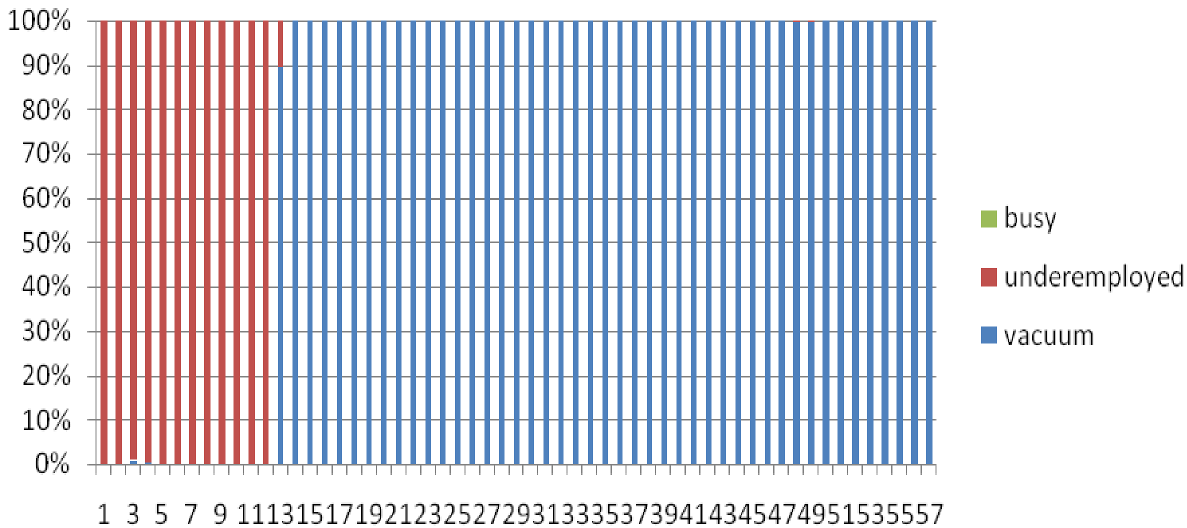

Figure 16: Measuring UM10.

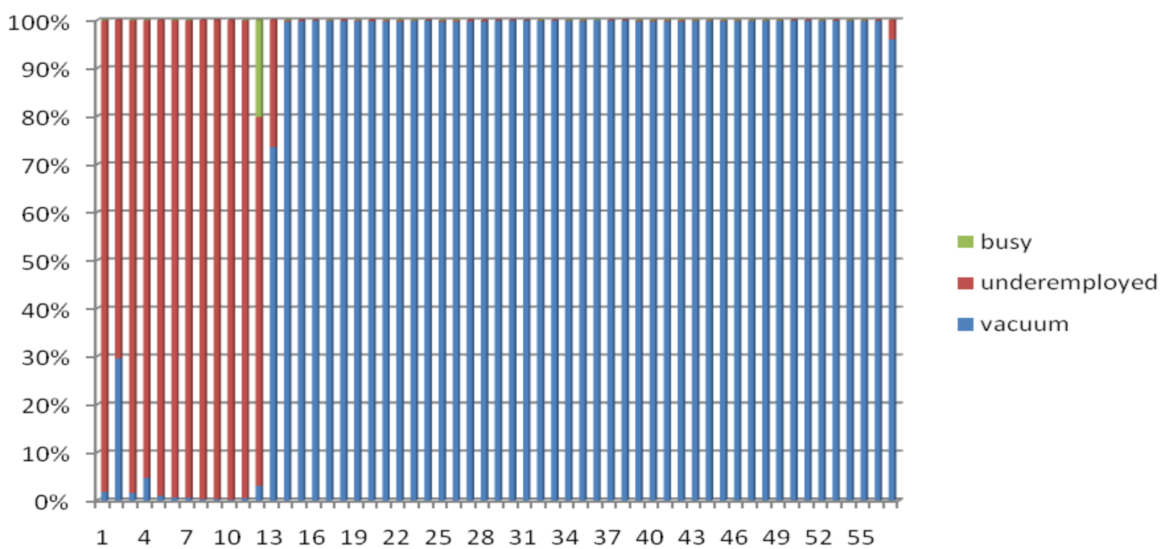

Figure 17: Trend.

roofs and sheds create reflection effects that modify the measured values, generating effects of radiation increased by three orders of magnitude.

Natural obstacles such as trees have different effects depending on the species concerned. Species whose leaf surface is approximately 15 cm^2 dominate the increase in radiation levels. In relation to radiation levels in the vicinity of the facility, a cone of low radiation is seen in an average of 30 m radius. This value is increased until a radius of 300 m approximately is achieved. A negligible decrease in the level of radiation at longer distances is observed.

In short, it is concluded that in a normal environment the level of radiation is practically constant in the vicinity of a half of a typical cell of 5000 mts. As such, we are not able to say that there are regions more exposed than others.

The sharing of the towers by the companies providing the service does not produce a significant increase in the radiation level in a tower comparatively sharing a company operated by a single tower.

On the other hand, differences are not observed either at sites with different technologies (2G, 3G LTE). Note that the maximum radiation level observed never becomes higher than that obtained in the vicinity of a mobile cell phone whose level of radiation reaches five times the maximum measured value in any cell phone location. It was verified that some measurements obtained at the base stations do not meet international safety standards. This situation motivates the following recommendations (De la

Cruz Mario, 2008):

- A base station antenna must be installed 10 (ten) meters above public access areas;
- Access areas to the public must be located within 10 m of horizontal antennas;
- For roof-mounted antennas, elevate the transmitting antennas above the height of people who may have to be on the roof;
- For roof-mounted directional antennas, place them near the edge of the roof and pointing to the outside of the building;
-Consider the pros and cons of large-aperture antennas and small aperture antennas;
- Take special precautions to keep higher-power antennas away from accessible areas;
- Keep antennas in places as far away as possible, although this may be contrary to local zoning.

Once data analysis is performed, we can conclude that the spectrum is underemployed with a reduced use in terms of occupation per channel. From our data, it is shown that the first thirteen channels have a 89% underemployment and 1.5% of employment in the various measuring points and times at which the measurements were made. The remaining 44 channels represents only 0.25 and 99.75% sub occupation without use, respectively.

For a deeper understanding of the spectral efficiency, as well as, analysis and geographical distribution in spectrum utilization factor installation of continuous recording of the spectrum on the campus of the university is recommended (Barnes et al., 2013). As a future research line in relation to the spectral efficiency, the use of cognitive radio systems in this scenario can be put under consideration (Beibei et al., 2011). Economical profit and technological issues need to be evaluated in order to reach a realistic conclusion.

REFERENCES

Recommendation (2011). ITU-R SM 1880, Geneva.
Technical manual Checking the spectrum ITU, Geneva.
Resolution 3690/2004 (Official Gazette No. 30524 10,11,04) National Commission of Communications, Buenos Aires, Argentina.
Standard ANSI/IEEE de (1992).
De la Cruz Mario F (2008).*"Introducción a los Sistemas de Telefonía Celular"*, Editorial Hispano Americana S.A.
Barnes SD, Jansen PA, Vuuren VY, B.T. Maharaj BT (2013). "Spectrum occupancy investigation: Measurements in South Africa," *Elseiver*, measurement, 46:3098-3112.Beibei WY, Ray K, Liu J (2011). "Advances in Cognitive Radio Networks: A Survey," *IEEE J.* 5(1):5-23.

Cite this article as:

Pablo N, Roberto B, Mario FC, Fernando GY (2017). Non-ionizing radiation and spectrum occupancy measurements. Acad. J. Sci. Res. 5(6): 103-114.

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