Evaluation of Non-Ionizing Radiation Emitted by FM Broadcasting and Free-To-Air TV Systems in the Municipality of El Crucero, Managua

Julio C. Cruz Icabalzeta, Gabriel E. Delgadillo Fernández, and Marvin R. Arias
Universidad Nacional de Ingeniería, Managua, Nicaragua
julio.cruz.ni@ieee.org, gdelgadillo@gmail.com, marvin.arias@uni.edu.ni

***Abstract*— The aim of this work is to provide an evaluation guide for the Nicaraguan telecommunications regulator Instituto Nicaraguense de Telecomunicaciones y Correos TELCOR to assess the Non-Ionizing Radiation NIR levels emitted by FM Radio and Free-To-Air TV broadcasting systems installed in the municipality of El Crucero, an empoverished municipality where 44 FM Radio and TV Broadcasting operators simultaneously transmit nearby populated areas, using measurement equipment available in TELCOR's mobile monitoring units. These mobile units, each equipped with an ESMB Monitoring Receiver, Antenna ADD-190 and Software ArgusMon 4.3, were made available for this investigation, alongside the personnel of Dirección de Calidad y Monitoreo del Espectro Radioeléctrico (DCAMER-TELCOR) for NIR measurement campaigns performed in 11 selected points in El Crucero. The measurements results show that the exposition to these emissions does not exceed 1% of ICNIRP's general public exposure limits in 7 points, and 5% on the rest.**

Keywords—Non-Ionizing Radiation; Broadcasting; Measurement

I. INTRODUCTION

Humans have always been exposed to electromagnetic fields (EMFs), since these are present in nature. However, technological development, particularly in telecommunications services, has increased human exposure to EMFs, specifically Non-Ionizing Radiation (NIR) generated by telecommunication antennas, causing public concern about its possible effects in human health [1].

The proven health effects are immediate and short-term, specifically heating in human tissue [2]. The current research focus is to demonstrate whether exposure over a long-term period, even at such low levels as not to cause significant temperature increase in human tissues, could cause harmful health effects [1]. This kind of exposure is common nearby broadcasting antennas, scenarios in which the people can not control their exposure to these radiations, unlike mobile phones in which the user can control its usage and therefore the exposure to its radiation.

In Nicaragua, the Ente Regulador de los Servicios de Telecomunicaciones y Servicios Postales de Nicaragua (TELCOR) (Nicaraguan Institute of Telecommunications and Postal Services), ensuring the benefit of the population, is responsible to verify that telecommunications installations in the country comply with appropriate parameters of NIR emissions. However, it's technical regulations make no reference related to human exposure to radiation emitted by telecommunication transmission systems antennas, and no review has been made since published. Besides, no exposure limits are established in Nicaraguan legislation [3] nor TELCOR has a NIR measurement guide that complies with international recommendations for its available monitoring equipment.

According to TELCOR's 2012 statistics, the most recent, 255 FM Radio and 21 Free-To-Air TV operators are registered nationwide, from which 44 radiobroadcasters and 10 television broadcasters are localized in department Managua. Over 40 of these operators have their principal transmission systems installed in El Crucero [4], formerly a district of municipality Managua and since 2000 an independent municipality of department Managua, consisting of 17 empoverished communities and an urban area of 8 small neighborhoods [5].

Due to its elevation over 900 m above mean sea level, and proximity to the capital Managua, as it can be seen Fig. 1, El Crucero is an ideal and the most important location for broadcasting systems in the Pacific Region of Nicaragua.

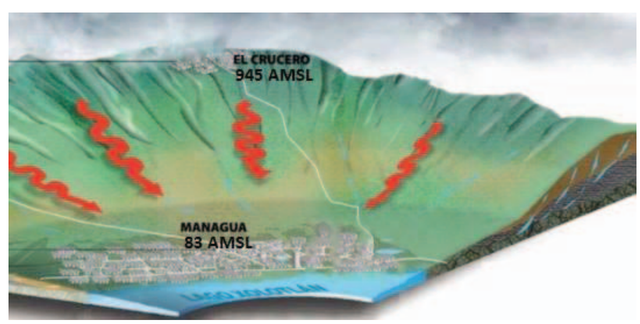

Fig. 1. El Crucero and Managua above mean sea level comparison.

Due to the amount of antennas operating simultaneously nearby population, it is possible to affirm that NIR exposure levels at El Crucero may be among the highest in the country. However, due to the abscense of exposure levels data, it's not possible to verify compliance with International Commission on Non-Ionizing Radiation Protection ICNIRP guidelines, the most adopted exposure limits by governments worldwide. Therefore, it is important to quantify this exposure at El Crucero.

Fig. 2. Some FM Radio and TV transmission systems visualized near houses in El Crucero.

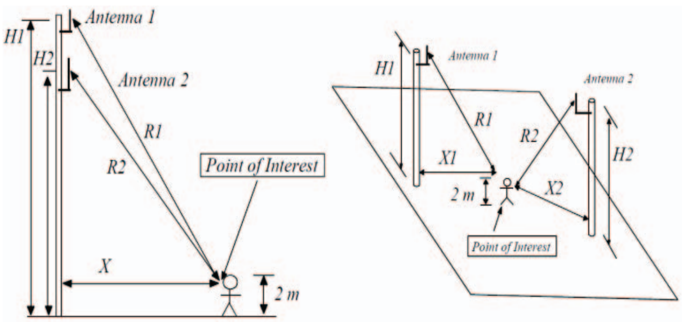

Fig. 3. El Crucero exposure scenario.

Considering the high number of sources and different antenna arrays per source, as seen in Fig. 2 and Fig. 3, besides the limited technical information available about their radiant systems, El Crucero is a complex scenario to implement an evaluation method other than measurement to evaluate exposure [6].

In this work, we will compare results obtained by NIR measurement campaigns which will take place at El Crucero using TELCOR's available monitoring equipment, with ICNIRP's general public reference levels [2], in order to verify compliance. For these measurements, we will develop a procedure guide following recommendations from International Telecommunication Union ITU and European Committee for Electrotechnical Standardization CENELEC, so similar campaigns can be performed nationwide.

II. Measurement Equipment

TELCOR's 2 mobile monitoring units, comprising a set of antennas, of several frequency ranges and different polarizations, and equipment for a wide range of monitoring applications [7], as seen in Fig. 4, were made available for this work.

Measurements were performed using an ESMB Monitoring Receiver, ADD-190 antenna, shown in Fig. 5, and a computer with ArgusMon 4.3 software installed in the mobile units.

Fig. 4. TELCOR's mobile monitoring unit, outside view (left) and inside view (right).

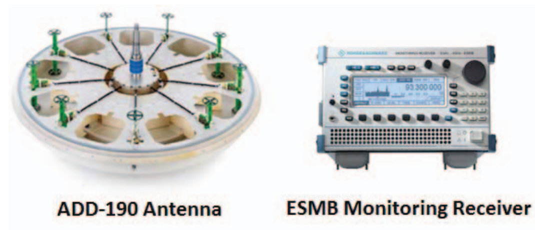

Fig. 5. Measurement equipment used.

The Rhode & Schwarz ESMB Monitoring Receiver operates in the frequency range from 20 MHz-3 GHz, and performs Electric Field Strength *E* (V/m) measurement by Frequency Selective Method.

The Rhode & Schwarz ADD-190 operates in the frequency range from 20 MHz-1.3 GHz, and is specially designed for direction finding applications. It consists of 9 highly linear active dipoles of approximately 0.2 m long, arranged in a circle with 0.91 m, thereby ensuring omnidirectional reception of vertically polarized electric field waves. It is fixed on the roof of the vehicle, at a 2.3 m height above ground.

The ADD-190 and ESMB Monitoring receiver are configured and controlled remotely via computer by ArgusMON 4.3 Rhode & Schwarz Software, as shown in Fig. 6.

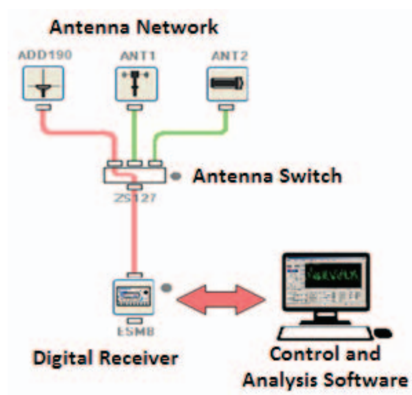

Fig. 6. Equipment Interconnection Diagram

The ESMB Receiver allows using different measurement modes. For this investigation, the Automatic Measurement Mode (AMM), which consists in a scheduled cyclical measurement routine, was selected. To implement AMM, a list of frequencies to be measured is created and a numerical database of the electric field strength levels measured for each frequency is automatically obtained, obeying a previously configured defined schedule and measurement parameters. This significantly reduces the evaluation time at each measurement point.

III. MEASUREMENT SETUP AND ENVIRONMENTS

This section describes the measurement set up that will be performed following the procedure shown in Fig. 7, which is based on EN 50492 [8]. Each step will be addressed in this work.

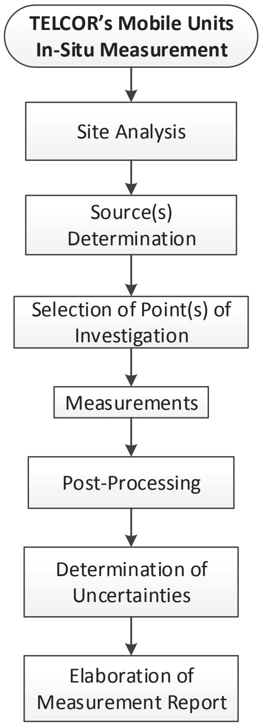

Fig. 7. In-Situ evaluation procedure used.

A. Site Analysis

According to the national census of 2005, the urban region of El Crucero is the most densely and highly populated part of the municipality, with 39.5% (5,404 persons) of the total population of the municipality (13,656 persons) . This human settlement is developed alongside the highway to Managua by reason of the benefits of being closer to the capital, and the services nearby [5]. Due to this importance, the urban part of El Crucero is the area of major interest in obtaining NIR exposure levels data.

B. Source Determination

To identify operators in El Crucero, TELCORs license web database was consulted [4], and complemented with information obtained by site visual inspection, FM Radio and TV security staff installations consulting, and a selective frequency quick scan. Using these methods, 36 FM Radio and 8 Free-To-Air TV operators installed in El Crucero were identified.

To implement AMM, a FM Radio Frequency List, consisting of 44 frequencies in the 88 MHz-108 MHz range , and a TV Frequency List, consisting of 16 Frequencies (video and audio carrier) in the 55 MHz–520 MHz range, were created. The additional 8 FM frequencies were considered to be certain of assessing non-identified FM Radio sources.

C. Measurement Environments

The points of investigation were chosen by visual and mapping inspection, giving priority to areas of social interest such as schools, parks, and other places of social agglomeration. The measurement locations selection criteria for mobile stations, established in [9], were:

- Distance between the receiving antenna and transmitting antenna must be in far field region, to avoid inductive coupling.
- The place of measurements must be sufficiently flat to approximate an ideal reflective or absorbent surface.
- The place must be free of obstacles that produce multiple reflections.
- All research points chosen must be located in accessible locations for road test vehicle.

Obeying these criteria, 11 measurement points were chosen, geographically distributed as shown in Table I and Fig. 8.

TABLE I. 11 SELECTED MEASUREMENT POINTS

Measurement Locations	Place
1	Barrio Carlos Fonseca
2	Barrio El Chorizo
3	Barrio Luis Alfonso Velásquez
4	Barrio Luis Alfonso Velásquez
5	Barrio Edgar Lang
6	Barrio Jonathan González
7	Barrio Edgar Lang
8	Barrio Juan José Quezada
9	Carretera El Crucero-Las Nubes
10	Mirador Las Nubes
11	Las Nubes

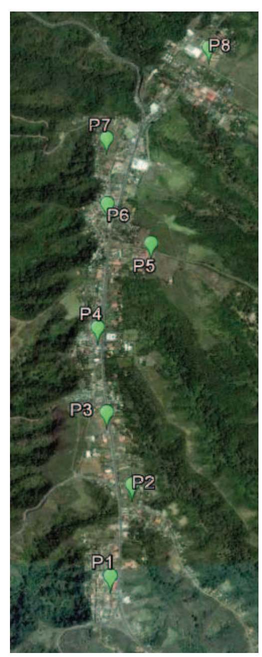

Fig. 8 Eight out of eleven selected points of measurement

D. Measurement Campaign

The steps to follow in NIR measurement campaigns using TELCOR's mobile unit equipment are detailed in the algorithm shown in Fig. 9. This procedure must be performed for each frequency list in each measurement point.

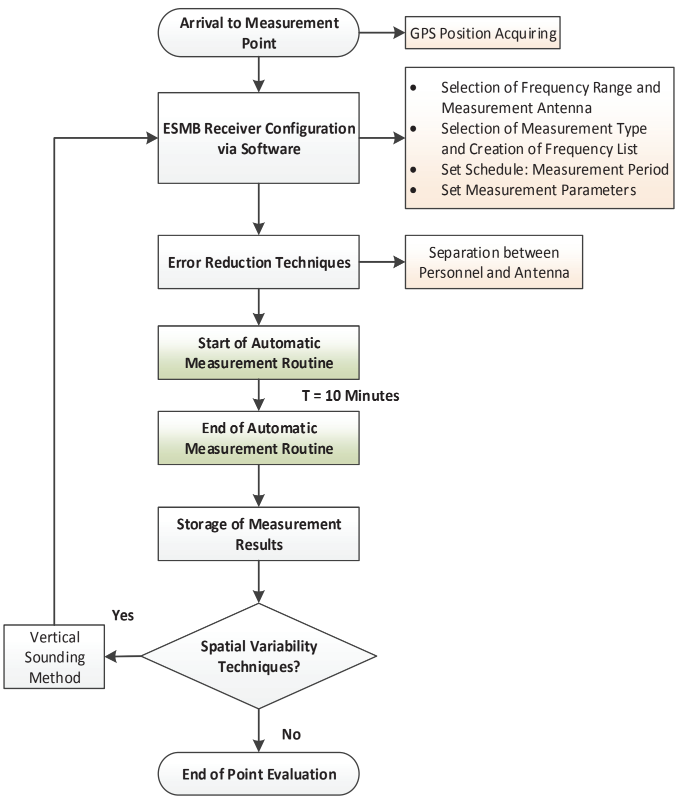

Fig. 9. In-Situ Measurement Algorithm to use with TELCOR's mobile unit equipment.

ICNIRP recommends an averaging time-period of 6 minutes [2]. However, since AMM is a cyclical measurement process, and several frequencies will be assesed, the selected measurement period in this investigation is 10 minutes to grant the acquisition of sufficient samples of *E* levels per frequency in case of any unexpected delay in the sampling time of 100 ms.

The configured parameters in the ESMB Receiver are shown in Table II.

TABLE II. ESMB RECEIVER MEASUREMENT PARAMETERS CONFIGURED

Parameter	Value
Detector Type	RMS
Demodulation Type	FM
Intermediate Frequency Bandwidth	120 kHz
Gain Control	Automatic Gain Control
Measurement Time (Sampling)	100 ms
Measurement Period	10 min

Fig. 10. Installing the HE 309 antenna to the mast.

Ideally, the measured quantities should be spatially averaged over the dimensions of a human body, by implementing spatial variability techniques during the measurements [10]. Vertical Sounding, which consists in performing measurements varying height of an antenna installed in a mast [9], is the appropriate spatial averaging method when using mobile units. This method was tested using an HE 309 active dipole antenna, as seen in Fig. 10, but it was discarded after measurement results showed considerable attenuation (>30 dBµV) when compared to previously obtained values with the ADD-190. Besides, this method would have implied extending an already limitied time per measurement point.

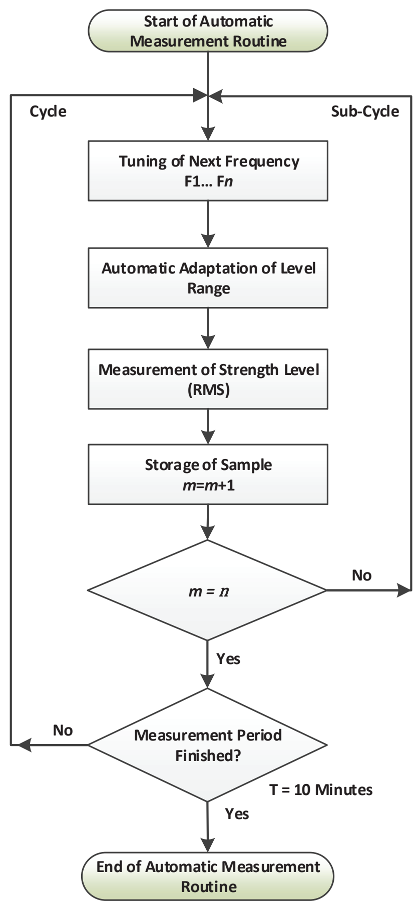

Fig. 11. ESMB Receiver AMM process

The tasks performed by the ESMB Receiver during the Automatic Measurement Routine are represented in the algorithm shown in Fig. 11. These procedure basically consists in acquiring various samples of Electric Field Strength Root Medium Squared RMS Levels for each frequency of the list, during the established measurement period.

Once the measurements had ended, the results are shown in an alphanumeric matrix displaying parameters of time and date, frequency and E levels in logarithmic scale $\mathrm{dB\mu V/m}$, as it can be seen in Fig. 12, consisting. Several samples of E are obtained for each frequency. For assessing human exposures, all the resulting data will be analyzed and processed using Microsoft Excel software.

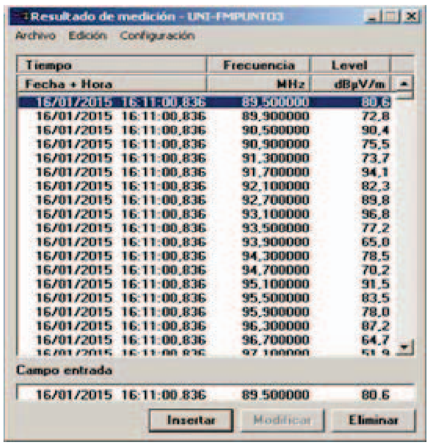

Fig. 12. ArgusMon 4.3 measurements results display

IV. DATA ANALYSIS AND POST-PROCESSING

The procedure for post-processing each measurement results database is shown in Fig. 13.

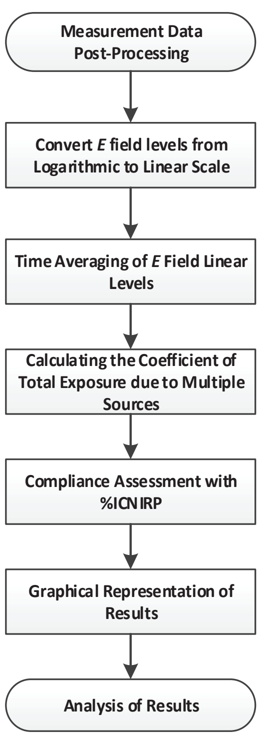

Fig. 13. Post-Processing procedure of measurement data

The post-process consists in the conversion, for each source, of all the E logarithmic levels into linear levels in order to perform a time averaging (arithmetic mean value) of its samples over the measurement period, by using (1);

$$E_i\ avg = \sum_{j=1}^{n} \frac{m_j}{n}$$

Where $E_i\ avg$, is the average electric field strength of a frequency i; m_j, is the value of a sample level j; n, is the total number of samples.

Once the average electric field strength for every source is determined, an adding of the contributions from all sources, known as Total Exposure Coefficient TEC [2], is calculated per each measurement point, using (2)

$$W_t = \sum_{i>1MHz}^{300GHz} \left(\frac{E_i}{E_{l,i}}\right)^2 \leq 1 \qquad (2)$$

Where E_i is the electric field strength of a frequency i; $E_{L,i}$ is the field strength reference level for a frequency i. If $W_t \leq 1$ condition is fulfilled, the site is in compliance with ICNIRP general public reference levels. The TEC of each measurement point is shown in Table III.

TABLE III. TOTAL EXPOSURE COEFFICIENTS (TEC) PER MEASUREMENT POINT.

Point No.	TEC Wt	% ICNIRP – General Public
1	0.00003	0.0030%
2	0.00001	0.0010%
3	0.00005	0.0050%
4	0.0001	0.0100%
5	0.0003	0.0300%
6	0.0003	0.0300%
7	0.002	0.2000%
8	0.0416	4.1600%
9	0.0381	3.8100%
10	0.0107	1.0700%
11	0.0165	1.6500%

Measurements in points 8 to 11 registered the highest exposure levels due to its proximity to the agglomeration of FM and TV installations, specifically alongside the highway from El Crucero to Las Nubes, where the population is less in comparison with neighborhoods near the measurement points 1 to 7.

TABLE IV. UNCERTAINTY BUDGET

Error Sources	Reference	Specific Uncertainty (dB)	Probabilistic Distribution	Divider. K_i	C_i	Standard Uncertainty (dB)
Measurement Equipment						
Calibration	Assumed	5	Normal	1.96	1	2.55
Isotropy	Assumed	5	Normal	1.96	1	2.55
Linearity	Assumed	5	Rectangular	1.73	1	2.89
Measurement Device	ESMB Receiver Datasheet	1	Normal	1.96	1	0.51
Noise	Assumed	3	Normal	1.96	1	1.53
Mismatch	Assumed	3	U-Shaped	1.41	1	2.12
Influence of Temperature and Humidity in Measurement Equipment	ESMB Receiver Datasheet	**0.5**	Rectangular	1.73	1	**0.29**
Enviromental Parameters						
Environmental Perturbance	EN50383	3	Rectangular	1.73	1	**1.73**
Body Influence	EN50492	2	Rectangular	1.96	1	**1.02**
Post-Processing						
Spatial Averaging	EN50492	10.7	Rectangular	1.73	1	**6.18**
Combined Standard Uncertainty					$u_C(y)$ **[dB]**	**7.17**
Expanded Uncertainty			Regular	1.96	U **[dB]**	14.05

E. Uncertainty Assessment

The reliability of the measurements is assessed by establishing an uncertainty budget taking into account all possible error contributions combined with an estimation for their uncertainty and its probability distribution [11]. This assessment is specially important when the measured values are very close to the exposure limits [12].

The uncertainty budget for this work is shown in Table IV and it considers the error contributions recommended by [13]. The standard uncertainties of all contributions are combined into one value named Combined Standard Uncertainty. This Combined Standar Uncertainty value is multiplied by a coverage factor of 1.96 to define an interval about the measured result that will encompass the true value with a 95% level of confidence. This result is called Expanded Uncertainty.

To ensure that the In-Situ measurements are in compliance with exposure limits, the total Expanded Uncertainty should not exceed 4 dB [11]. Since some values of our uncertainty budget were assumed, due to the abscene of equipment calibration certificates, the expanded uncertainty may be either underestimating or overestimating the real value.

With the purpose of knowing what should be the maximum value of expanded uncertainty for which the measurements do not comply with the exposure limits, the following expression was developed based on the equation for reduction of limit values by uncertainty margins from [11]:

$$U \geq 2 * (X_{lim} - X_{meas}) + 4 \quad (3)$$

Where U is the expanded uncertainty of the measurement; X_{meas} is the measured value; X_{lim} is the applied limit. In this work, the maximum E level measured is $E_{102.3\text{MHz}}$ = 4.125 V/m, from Point No. 8. Introducing this value in (3), we can estimate that the maximum tolerable uncertainty is:

$$U \geq 2*(28 - 4.125)+4$$

$$U \geq 51.75\text{dB}$$

As we can see, if the measurement of highest E value in the campagins would demand an expanded uncertainty of 51.75 dB to doubt of its compliance, the rest of measured values would demand an even higher expanded uncertainty, thus is possible to affirm that, even though the measurement equipment used is not calibrated, the measurements are in compliance with exposure limits, considering that the expanded uncertainty shown in Table IV is below the margin defined in (3).

V. CONCLUSIONS

In this work, we have measured NIR emitted by FM Radio and Free-To-Air TV broadcasting systems at El Crucero, using TELCORs mobile monitoring units, for whose equipment an evaluation guide was developed and implemented. Results obtained at 11 selected measurements points at El Crucero show that exposure levels are in compliance with ICNIRP's general public reference level by not exceeding 1% in 7 points, and 5% on the rest, thus creating the first NIR database in the municipality. The developed evaluation guide can be reproduced nationwide in other places where the concern due to the agglomeration of FM Radio and Free-To-Air TV broadcasting systems deserve an exposure limits compliance verification.

ACKNOWLEDGMENT

The authors would like to acknowledge MSc. Oscar Napoleón Martínez (UNI), Dr. B. Vulevic (University of Belgrade) and DCAMER department staff (TELCOR) for their useful comments and valuable support of this work.

REFERENCES

[1] WHO, World Health Organization, Establishing a Dialogue on Risks from Electromagnetic Fields, Geneva, 2005, p. 65.

[2] ICNIRP, International Commission on Non-Ionizing Radiation Protection, ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz), vol. 74, Munich, 1998.

[3] O. Martínez; M. Arias; Análisis Sobre Exposición de Personas a Campos Electromagnéticos Emitidos por Redes Celulares Desplegadas en Ambientes Urbanos. Universidad Nacional de Ingeniería, Managua Nicaragua, 2013.

[4] TELCOR, Instituto Nicaragüense de Telecomunicaciones y Correos. Operadores de Servicios [Online]. Available: http://www.telcor.gob.ni/Operadores.asp [Last access: 06 30 2016]

[5] Mayoral of El Crucero. Información Municipios AMUSCLAM [Online]. Available: https://sites.google.com/site/informacionmunicipiosamusclam/home/municipio-el-crucero [Last access: 06 30 2016]

[6] FCC, Federal Communications Commission Office of Engineering & Technology, "Multiple-Transmitter Sites and Complex Environments," in Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields, 97-01 ed., Washington, D.C., 1997, p. 32.

[7] Rohde & Schwarz, "Nationwide radiomonitoring system for Nicaragua," News from Rohde & Schwarz , vol. 42, no. 176, p. 45, 2002.

[8] J. Wiart, "ITU-T Workshop “Human exposure to electromagnetic fields (EMFs)”," in Mobile and Base Station standards developed by CENELEC, Geneva, 2007.

[9] ITU, International Telecommunication Union, Recommendation ITU-R BS.1195-1: Transmitting antenna characteristics at VHF and UHF, Geneva, 2013.

[10] ITU, International Telecommunication Union, Recommendation ITU-T K.61: Guidance on measurement and numerical prediction of electromagnetic fields for compliance with human exposure limits for telecommunication installations, Geneva, 2008.

[11] ITU, International Telecommunication Union, Recommendation ITU-T K.91: Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields, 1.0 ed., Geneva, 2012.

[12] B. Vulevic and T. Stalevski, Broadband measurements of RF electromagnetic fields: an example for spatial averaging and uncertainty of measurement, Belgrade, 2015.

[13] ITU, International Telecommunication Union, Recommendation ITU-T K.83: Monitoring of electromagnetic field levels, 1.0 ed., Geneva, 2011.