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Estimation of Frequencies for National Shortwave Network with Automatic Link Establishment Equipment

Estimación de frecuencias para la Red Nacional de Onda Corta con equipo de establecimiento automático de enlace

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Abstract

Transmission over High Frequency (HF) is a very important alternative to the wired communication. Though it offers narrow bandwidths, long distances are reachable with it so the mechanism is commonly used as a backup connection for exceptional situations. The Automatic Link Establishment (ALE) technique is a new solution that tries to release the HF operators from the arduous task of finding the most favored communication frequency. Recently, a wireless HF network based on ALE has been proposed for interconnecting the western, central and eastern Cuban regions with the Havana capital city. While the technology ensures high stability in communications, it requires the a priori configuration of a frequency set for each established link. Authors of the present paper use the VOACAP software to predict the ten optimal communication frequencies for the period 2014 - 2018, in an analysis that allows the adaptation of the chosen set in an annual or monthly basis, depending on user needs. The results are also compared with estimates for the years 2012 and 2013, completing thus the progression analysis of the general behavior and its dependence on ionospheric conditions.

Keywords

HF Propagation, Frequency Prediction, ALE, Short Wave Links, VOACAP.

Resumen

Las transmisiones por HF (High Frequency, Alta Frecuencia) son una alternativa muy importante a la comunicación cableada. Aunque disponen de ancho de banda reducido, pueden alcanzar largas distancias, por lo que se utilizan frecuentemente como conexión de respaldo ante situaciones excepcionales. La técnica de establecimiento automático del enlace (ALE) es un mecanismo novedoso que intenta librar a los operadores de HF de la ardua tarea de encontrar la frecuencia de comunicación más favorecida. Recientemente se ha propuesto una red basada en dispositivos ALE que interconecta por HF a las zonas occidental, central y oriental con la capital cubana de La Habana. Si bien la tecnología ALE garantiza una alta estabilidad en las comunicaciones, requiere de la configuración a priori de frecuencias para los enlaces. Los autores del presente artículo, utilizan la aplicación informática VOACAP para predecir las diez frecuencias óptimas de comunicación en el período 2014 – 2018, en un análisis que permite la adaptación del conjunto elegido en una base anual o mensual, según las necesidades del usuario. Los resultados son comparados también con cálculos para los años 2012 y 2013, con los que se completa el análisis de la progresión del comportamiento y de su dependencia de las condiciones ionosféricas.

Palabras clave

Propagación HF, Predicción de frecuencias, ALE, enlaces por onda corta, VOACAP.

1. INTRODUCCIÓN

Radio communications covering the interval between 3 and 30 MHz are referred to as HF (High Frequency) communications. Through they are limited regarding bandwidth; they allow covering large distances reaching sites at thousands of kilometers (1). The short-wave transmission, as it is also known, employs the ionosphere as a propagation medium which brings both advantages and disadvantages to the mechanism. Figure 1 illustrates the ionospheric phenomenon.

The main advantage given by ionospheric transmission is the autonomy in the communication, highly desired feature in armed conflicts or natural disasters' conditions (2). Autonomy implies independence of any facility provided by third parties to establish the link.

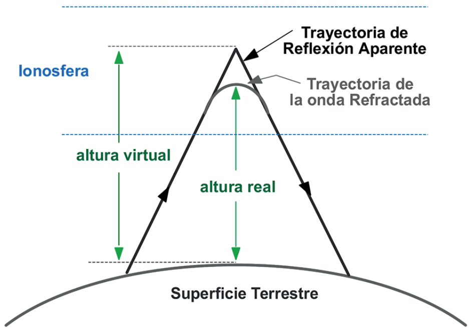

Figure 1: Ionospheric propagation phenomenon.

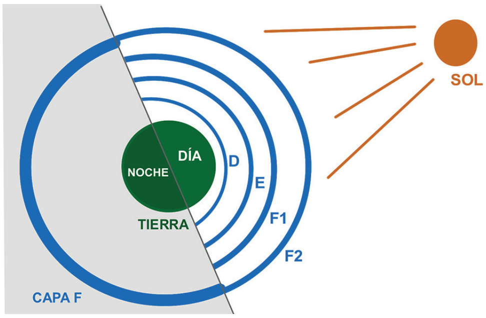

Figure 2: Ionospheric layers.

The main disadvantage on the use of the ionosphere is the obtained fluctuating reception quality since the user is operating over a medium which has essentially three types of variations: annual, daily and sudden. Ionospheric layers' conditions are mainly governed by solar activity so understandably changes occurring in the sun are reflected in propagation. Figure 2 shows layers that compose the ionosphere (3).

The D layer, between 50 and 80 km of altitude, often acts as an attenuator (4). Instead, the E layer may behave as an attenuator or as a reflector (5) and it can be found between 90 and 120 km, although greater heights have been identified at Cuba. F1 and F2 layers are distinguishable during the day, being the dividing border at 250 km altitude; while at night they merge into a single layer called F layer. The F layer, both in daytime and nighttime configuration, is the most commonly used in HF links, which usually perform more than one hop (6).

As a solution to the problem of the fluctuating quality of communications, the Automatic Link Establishment (ALE) technology was created. This technique's propose is to free operators from the arduous task of finding the Frequency for the Optimal Transmission (FOT) in a changing environment (7). When working with traditional shortwave equipment, experience operators are required to find the preferred communication channels which are favored by temporary ionospheric conditions. Instead, ALE technology allows the configuration of a set of frequencies between which the most privileged will be chosen in real time operation mode.

1.1 Motivation and contributions

The creation of a national ALE link has been proposed in order to replace the existing technology. In an initial phase of the project, the communication between the Havana Cuban capital city and the western, central and eastern parts of the country represented by the provinces of Pinar del Rio, Villa Clara and Guantanamo, was conceived. Figure 3 shows the approximate geographical positions and distances between sites. The advantages, cost and others subjects related to the design of the ALE network were discussed in (8).

For implementing the links, logarithmic periodic antennas, such as shown the one shown in Figure 4, are used. This type of antenna consists in a succession of radiant elements whose mutual distances and resonance frequencies are in geometric progression (9). Its main advantage is given by the fact that its fundamental parameters (input impedance, gain, radiation pattern) remain practically constant through the whole working bandwidth (10).

With the purpose of achieving the desired connection, four devices model IC-F8100, able to implement ALE, were purchased from ICOM manufacturer. These devices allow the introduction of ten working frequencies among which the best is selected according to channel conditions. Although experienced operators may suggest some frequencies, a study is needed in order to find precise values that ensure that the equipment operates with maximum efficiency.

Figure 3: Geographical location for the proposed ALE network.

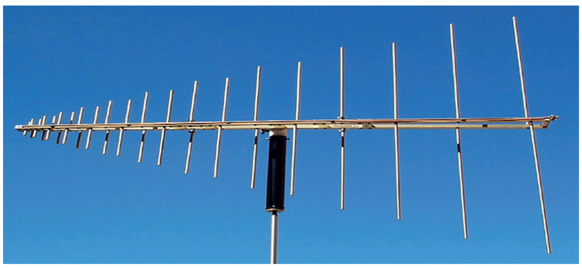

Figure 4: Periodic logarithmic antenna

So, finding the best ten frequencies was the aimed objective of the authors of this research. To complete it, they used the computer application VOACAP (Voice of America Coverage Analysis Program) as a tool to predict the links' behavior, computing thus the Optimal Operation and Maximum Usable Frequencies (MUF).

For the correct prediction of the searched values, all link details were introduced in VOACAP. These details are shown in section two called "Materials and Methods". Also in this section, a brief explanation of the IC-F8100's features and the ALE technique are exposed.

In Section three, under the name of "Results and Discussion", the calculated values are summarized in tables given the impossibility of showing the whole amount of information obtained. In addition, for each link a fixed set of ten recommended communication frequencies, valid until 2018, is provided. However, the results also allow the adjustment of the set's configuration in an annual or monthly base. In this sense, it worth highlighting the significant differences founded between the optimal frequencies to be used in the summer months in comparison with the rest of the year. Finally, estimates for 2012 and 2013 are also provided, completing thus the progression analysis of the general behavior and its dependence on ionospheric conditions.

2. MATHERIALS AND METHODS

The current section is divided in four sub-sections. In the first and the second of them, the basic features of the IC-F8100 devices and the ALE technique are presented. These first two sub-sections are conceived to make the reader understand the basic operation of the technology.

The other two sub-sections are dedicated to the presentation of the VOACAP computer application and the description of the procedure's details. As a result of the experiment, the MUF and FOT are obtained for each of the links for every month in the period from 2012 to 2018. This information is provided in Section three.

2.1. IC-F8100 Ale devices

The IC-F8100 device, manufactured by ICOM, has a small size and weight (about 3.8 kg) as it is characteristic of ALE radios. His external appearance is shown in Figure 5.

Besides the specifications of Automatic Link Establishment, it implements all the functionalities conceived for a conventional device, being well distinguished in the user interface both operating modes. The IC-F8100 dispose of an output power of 125 W for a complete voice duty cycle and allows achieving a duty cycle of 25% for data transmission, as well as up to five minutes of continuous emission. Despite its many features, the IC-F8100 is designed for the user to conduct its operations in a simple way. It has a screen that can display a great deal of information as shown in Figure 6.

The IC-F8100 is capable of performing multiple modulations among which the SSB (Single Side Band), Amplitude Modulation (AM) and Continuous Wave (CW) are found. Its general coverage reception goes from 500 kHz to 29.999MHz; while the transmission is possible between 1.6 MHz and 29.999MHz. Moreover, the functionality of Automatic Gain Control (AGC) stabilizes the receiver's gain to produce a constant audio output level even when the received signal strength varies being affected by fading.

Figure 5: IC-F8100 device from ICOM manofacturer

2.2. Ale features

The ALE functions, executed by the IC-F8100, are based on four fundamental principles: ionospheric sounding, Link Quality Analysis (LQA) matrix, Automatic Channel Selection (ACS) and channel scanning (7).

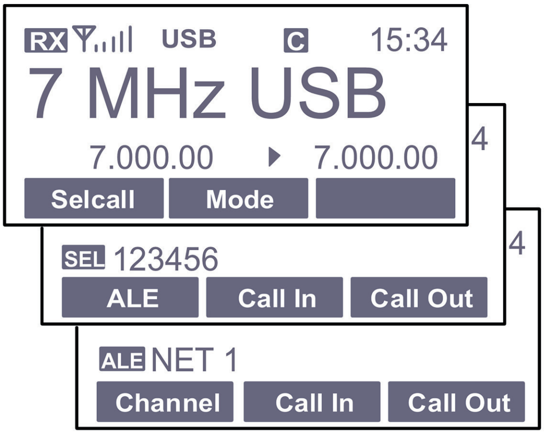

Figure 6: Device's windows showing several working modes.

By using sounding, the devices receive updated information on the status of the propagation channel at each frequency (1). Since the state of sounding partially obstructs the operation, transmission cycles are typically scheduled every 1 or 2 hours. The information obtained from the survey is stored in the LQA matrix in the form of active inputs (11), since the signal emitted to space is only intended to collect data on the state of the medium. Passives entries are also kept in the LQA matrix, obtained after performing measurements on user's messages. Even though the main objective of these messages is to carry the client's data, they provided useful information on the state of the ionospheric channel if the right tests are executed on them.

Once the matrix is filled, an ACS algorithm is executed whenever a transmission is requested, selecting thus the preferential propagation frequency. The initial selection of the channel is performed by the station that starts the conversation. However, the receiving station may request the use of an alternative frequency if the quality offered by the former is not acceptable.

To complete the diagram, the ALE protocol implements the constant scanning of the frequencies introduced into the LQA matrix. When the scan is started, unless the operator manually re-configures the system, the first channels that will be tested are those most benefited by the propagation conditions (12). Therefore, for the IC-F8100 devices, reception is possible in any of the ten established frequencies as the procedure ensures the constant search for remote broadcasts. However, the selection of the set of ten frequencies to establish communication is left free to the operator. Precisely, for finding the best ten, authors use the VOACAP software.

2.3. VOACAP software

In order to analyze the performance of HF circuits, several organizations have developed computer software models. The application IONCAP (Ionospheric Communications Analysis and Prediction Program) quickly became one of the most accepted and used in predicting models for short wave. However, it was revealed that it offered a poor performance in the polar regions and the structure of the electron density profile that it used was obsolete (13).

In response to its shortcomings, two direct descendants emerge: VOACAP and ICEPAC (Ionospheric Communications Enhanced Profile Analysis and Circuit). The second is a direct implementation of Recommendation 533 of the International Telecommunication Union (ITU) (14).

The VOACAP program was developed by the ITS (International Telecommunications Society) and has approximately 30 different output options. Most of the changes in the program improve the calculation speed; besides IONCAP's coding errors were corrected and input and output graphics were improved.

ICEPAC software represents another viable option as it has 29 different output options. It is very similar to VOACAP, as it increases the ability to predict differences in the ionosphere allowing the selection of the optimal frequencies, antennas and other circuit parameters. However, ICEPAC was not as extensively validated as VOACAP and unlike the latter, does not take into account a smoothing function between short and long paths for all distances between seven and ten km. Once these distances are reached, there is an abrupt transition between the short and long paths. Therefore, in some circumstances, if a remote link is calculated a control point can be found in the ionosphere with a discontinuity of almost ten dB halfway, causing artificial loss of signal to noise superior to 23 dB, while the model used by VOACAP finds a weak but detectable signal, which supposes the occurrence of a dispersive propagation mechanism (14).

The above-mentioned applications provide essentially the same results. In this project VOACAP was selected as a reliable and useful tool in the planning and identification of the best frequencies for HF transmissions taking into account the variations during the four seasons, the differences in solar activity, the hours of the day and the geographic location. VOACAP incorporates a user-friendly graphical interface with which the input variables can be easily modified getting thus the desired results (14).

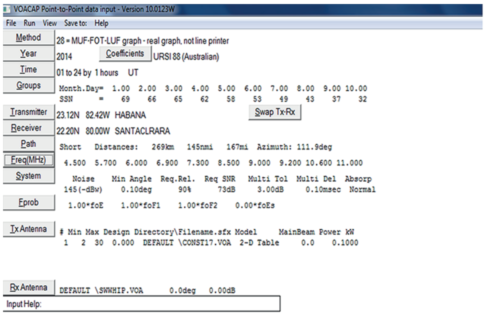

Figure 7: VOACAP's main screen.

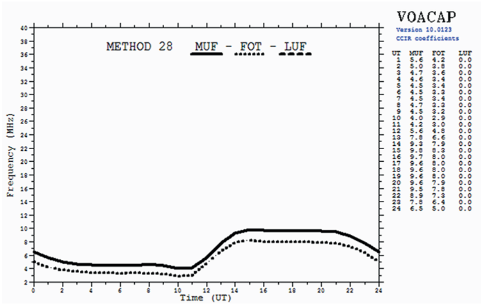

Figure 8: Behavior of an HF link during a whole month divided in hours.

Table 1: Estimation of sunspots in the period 2012-2018 (16).

YEAR/ MONTH	JAN	FEB	MAR	AP	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
2012	65.5	66.9	66.8	64.6	61.7	58.9	57.8	58.2	58.1	58.6	59.7	59.6
2013	58.7	58.4	57.5	57.8	59.8	62.6	65.4	68.9	73.1	75	73.6	70.8
2014	68.9	66.4	64.7	62.1	57.8	53.3	48.5	43.2	37.3	32	29.2	29.5
2015	28.6	27.3	26.1	24.8	23.8	22.7	21.3	20	18.8	17.9	17.1	16.5
2016	16.1	15.7	15.5	15.5	15.3	15	14.7	14.2	13.7	13.2	12.5	11.7
2017	11	10.3	9.8	9.4	9.1	8.9	8.9	8.8	8.3	8	7.8	7.6
2018	7.4	7.2	7	6.8	6.6	6	5.8	5.6	5.4	5.2	5	4.8

For performing the study, three hours were selected corresponding to habitual communications: 9am, 2pm and 8pm. The transmission power assumed was 500 Watts for all cases, following also a common practice for usual emissions. In addition, sunspots' values introduced in the software are offered in Table 1.

3. RESULTS AND DISCUSSION

As a result of performed calculations, a complete characterization of propagation among Cuban provinces of Pinar del Río, Villa Clara and Guantanamo in relation with the Havana capital was obtained. Charts for the three mentioned links are presented in the current paper, but the whole content of the study is not offered. To access it, please refer to the extended version of the research (7).

Starting the presentation of the results, in Figure 9 the MUF and FOT are displayed for the Havana-Villa Clara link at 9 AM. As it can be seen, the curves follow a monthly variation pattern that is repeated every year, placed over an annual decrease consistent with the fall of solar activity shown in Table 1. Note that the maximum MUF appears in November 2013 for a frequency of 11.2 MHz.

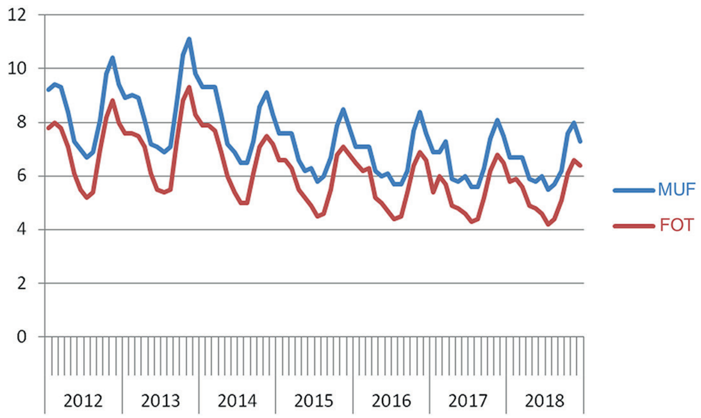

Figure 9: Calculation of the MUF y and the FOT for the Habana-Villa Clara link.

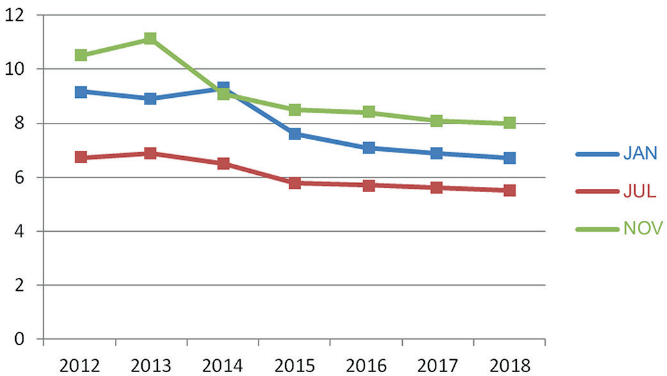

Figure 10: Behavior of the FOT for some remarkable months in the Havana-Matanzas link.

The FOT for some remarkable months in the Havana-Villa Clara connection is provided in Figure 10. It is observed that in the month of November is when preferential propagation occurs at higher frequencies; while in July the favored value drops significantly. Moreover, the behavior in January is illustrated as a reference for the average characteristic that prevails in most of the year.

The monthly variation of the MUF and the FOT, evidenced in Figure 9 for the Havana-Villa Clara link, can be also appreciated in Figure 11 that corresponds to the Habana-Pinar del Rio link. Here the frequencies for each of the months of 2013 at 2PM are plotted. In general, differences between the warmer months of the year and the rest were founded for all the studied links.

Continuing the analysis of the Pinar del Rio-Havana connection, the annual variation of the maximum and optimum frequencies for the months of October and July are revealed in Figures 12 and 13. Following the tendency visible in Figure 9 for Villa Clara, the decrease is also evident in the case of Pinar del Río, both in months where the communication frequencies are high and low. As can be seen, changes in the MUF and FOT in a period of six years are around 2 MHz.

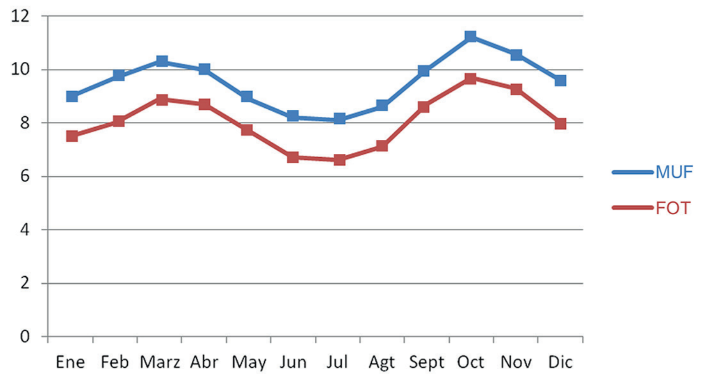

Figure 11: Variation of the MUF and the FOT through 2013 for the Habana-Pinar del Río connection at 2PM.

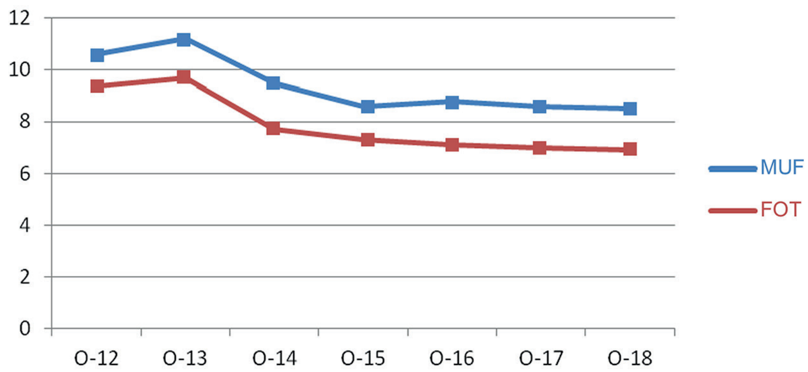

Figure 12: Annual Variation for October.

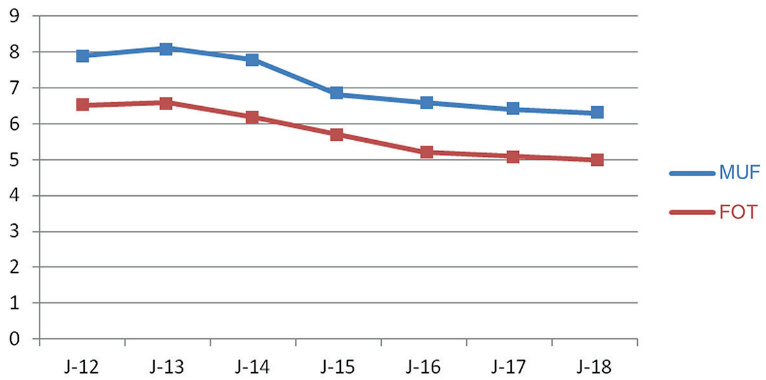

Figure 13: Annual Variation for July

Furthermore, the behavior of the communication frequencies for Havana-Guantanamo link at 8PM is illustrated in Figures 14 and 15 for all the months of three different years. Note the difference in variation between the first six months and the rest, as the years pass-by. While there is very little change in the period from January to June in the MUF and FOT between 2012 and 2014, between July and December the transition is more perceptible. However, when the year 2018 arrives both periods are quite different from 2012. The lack of uniformity in the variation of the MUF and the FOT over the years reaffirms the fact that ionospheric propagation laws are difficult to predict accurately using a simple model.

It is remarkable, in Figures 14 and 15, the fact that variation of the maximum and optimum frequencies is less significant in the months between June and August. The explanation for this behavior could be found in the high constant ionization of the ionosphere due to the effect of the sun in the traditionally warmer months.

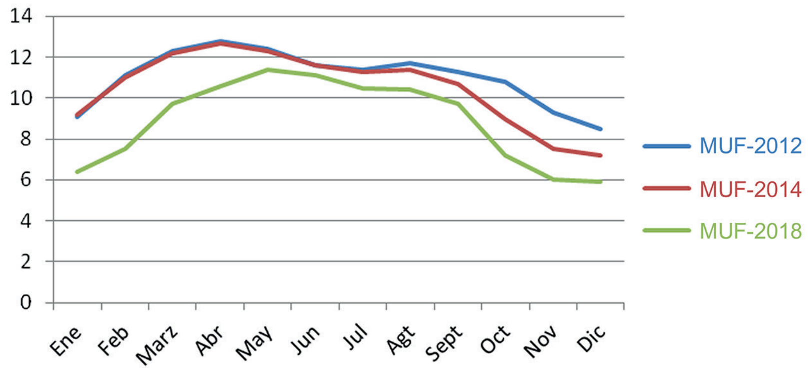

Figure 14: Monthly values for MUF in 2012, 2014 and 2018 for the Havana-Guantanamo link.

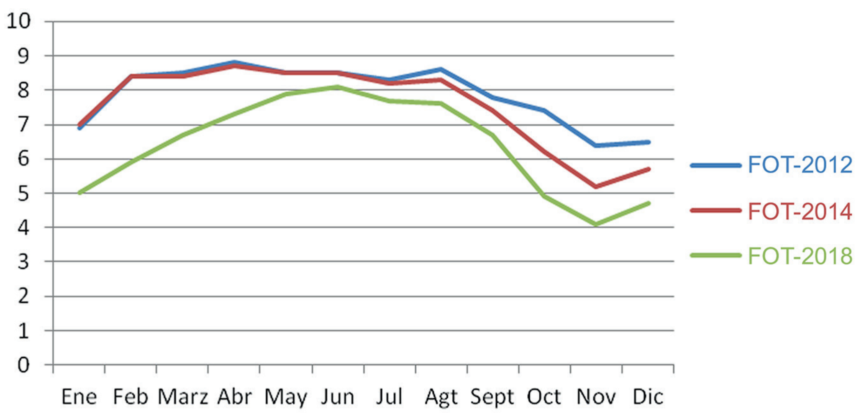

Figure 15: Monthly values for FOT in 2012, 2014 and 2018 for Havana-Guantanamo link.

Finally, after explaining the key points of the study, the frequencies proposed by the authors to ensure ALE communication between the selected provinces until 2008 are shown in Table 2. They allow operating all year long under the warranty of finding, with a high probability, one of the most favored communication frequencies. Please note that some selections were made to avoid falling into conflict with services implemented by third parties that are not described in this document.

Table 2: Frequency selection for national HF communication.

LINK/FREQUENCY	1	2	3	4	5	6	7	8	9	10
HAB-PINAR DEL RÍO	4,5	5,7	6	6,9	7,3	8,5	9	9,2	10,6	11
HAB-VILLA CLARA	5,3	6,2	7,5	7,9	8,4	8,8	9	9,6	10,4	11
HAB-GUANTÁNAMO	4,3	5	5,7	6,2	7	8,8	9,7	10,1	11,3	12,5

The selection offered in Table 2 leads to the configuration of the equipment with a permanent and acceptable option until 2018. However, if a more efficient solution is to be implemented, configuration options may be reprogrammed every year or every month, using the values calculated in this research. Note that frequently reconfiguration can significantly improve the quality of communication by taking into account the marked monthly variations found in the investigation.

4. CONCLUSIONS

The ten best frequencies for three HF ALE links communicating the provinces of Pinar del Rio, Villa Clara and Guantanamo with the Havana Cuban capital were estimated. The results were obtained for every month in the period 2012-2018 using the VOACAP software recommended by the ITU for estimates on shortwave propagation. To implement the links with four IC-F8100 devices, an extensive study of the ionospheric propagation was also offered, which allows adapting the selection of the set of frequencies in an annual or monthly basis, operating thus at a maximum efficiency level.

5. REFERENCES

1. National Telecomications and Information Administration (NTIA); Institute for Telecomunications Sciences (ITS). High Frequency Radio Automatic Link Establishment (ALE) Application Handbook; 1998 [visited 2014 June]. pp 303. Available at: http://www.n2ckh.com/MARS_ALE_FORUM/NTIA_HIGH_FREQUENCY_ALE_RADIO_APPLICATION_HANDBOOK.pdf

2. Hernando Rabanos J M. Transmisión por Radio. 6th edition. Spain: Editorial universitaria Ramón Areces, 2008, pp. 643. ISBN: 978-84-8004-856-9.

3. Richards J A. Radio Wave Propagation An Introduction for the Non Specialist. 6th edition. Germany: Springer; 2008, pp. 131. ISBN: 978-3-540-77124-1.

4. Seybold J. Introduction to RF propagation. United States: Wiley-Interscience; 2005, pp. 348. ISBN: 978-0-471-65596-1.

5. Schunk R. Ionospheres Physics, Plasma Physics, and Chemistry. United Kingdom: Cambridge University Press; 2009, pp. 642, ISBN-13: 978-0-511-63489-5.

6. Haslett C. Essentials of Radio Wave Propagation. United Kingdom: Cambridge University Press, 2008, pp. 215, ISBN-13: 978-0-511-37112-7.

7. Lorenzo Rodríquez Y, Gutiérrez Vázquez Y. Establecimiento Automático del Enlace (ALE) como solución a las Comunicaciones por Onda Corta en Cuba [Tesis]. La Habana, Cuba: Instituto Superior Politécnico José Antonio Hecheverría. Facultad de Ingeniería; 2014.

8. Machado Fernández J R, Gutiérrez Vázquez Y, Lorenzo Rodríquez Y, León Rosich D. Propuesta de Red Nacional de Onda Corta en Cuba empleando equipamiento de Establecimiento Automático del Enlace. Ciencias Holguín. 2015 Enero-Marzo, ISSN: 1027-2127.

9. Balanis, C. Modern Antenna Handbook. United States: John Wiley & Sons; 2008, ISBN: 978-0-470-03634-1.

10. Ornetta V C. Diseño y fabricacion de una antena logaritmica periodica 200-1000 MHz [Tesis]. Perú: Universidad San Marcos. Facultad de ingeniería; 2005.

11. ICOM. IC-F8100 HF Transceiver Instruction Manual; 2011 [visited 2014 June]. pp 60. Available at: http://www.icomuk.co.uk/files/icom/PDF/productManual/IC-F8100_um.pdf

12. INTERNATIONAL TELECOMMUNICATION UNION (ITU). International Telecommunication union (ITU). Standard, Interoperability and Performance Standards for Medium and High Frequency Radio Systems; 2011 [visited 2014 May]. pp 584. Available at: http://hflink.com/standards/ALE_standard_188_141B.pdf

13. Ramírez Castelan J R. Implementacion de la recomendacion UIT-R 533 para la prediccion de frecuencias en HF [Tesis]. México: Escuela Superior de Ingeniería Mecánica y Eléctrica Zacatenco; 2010.

14. International Telecommunication Union (ITU). VOACAP, propagation analysis and prediction program; 2012 [visited 2014 June]. Availble at: http://www.astrosurf.com/luxorion/qsl-soft-voacap.html

15. VOACAP software official website [Web Site]. 2013 [visited 2014 March]. Available at: www.voacap.com

16. Predictions on sunspots [Web Site]. 2014 [visited 2014 May]. Available at: www.ips.gov.au