Design and Experimentation of an Energy Detector for FM Radio Signals in Cognitive Radio

Andy Vega-León, Francisco Narváez, Juan Ochoa-Aldeán

Abstract: The present work shows the design of an energy detector, which is intended to measure the energy contained in FM radio frequency signals in the city of Loja generating prior information for the possible action of a Cognitive Radio transmission system (RC) in that band. The computer tool used to achieve the proposed design is MATLAB. For its operation and interaction with the FM electromagnetic environment, previous data derived from the spectral evaluation carried out in preliminary studies executed within the reference city are included. At the end of the work, a view of the behavior of the detector with real signals is obtained, allowing to obtain detailed data that evidences the spectral underutilization in this communication band opening possibilities of spectral optimization through RC.

Keywords.- Spectrum, Energy, Radio, Cognitive, Frequency

I. INTRODUCTION

The current wireless communications systems suffer from spectral saturation problems [1]. As a provisional measure in several countries, as in the case of Ecuador, it is decided to grant the spectrum through public tenders among the different applicants to the portion of spectrum that is available. Preliminary studies carried out in 2011 [2] and 2015, show results that open up the possibility of applying RC wireless technologies such as the transmission of data in television white spaces called TV white space. In the Loja canton, it was detected that the use of the licensed frequency bands is deficient or underutilized, becoming free up to more than 50% of the time. In the case of FM broadcasting systems, it is pointed out that even 70% of the spectrum becomes available. It is important then to corroborate these investigations by adding a new stage of analysis of the frequency spectrum modulation occupation process by detecting the energy contained in the electromagnetic radiation that injects to the Cognitive Radio system preliminary information prior to the process of conducting a transmission without interrupting or interfere with the licensed frequencies.

Within the radio propagation energy detection systems there are different aspects or characteristics to consider; for example, noise power and level of knowledge of the signals; this generates three types of detectors. Those of filter adapted in case of knowing the type of signal transmitted; On the other hand, if there is the presence of signals with periodicity parameters, the detection method is used by cycloestationary processes and finally the energy detector whose method does not need more information of the transmitted signal. This last method becomes the objective of the present study.

Revised Version Manuscript Received on February 15 2019.

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II. PROCEDURE FOR PAPER SUBMISSION

A. *Background*

As previously described, the technological needs of society require innovation in telecommunications systems, which leads to an increase in the demand for spectrum in wireless systems. In other words, there is a high demand for the radio spectrum compared to an apparently limited capacity. Numerous campaigns reveal that a large part of the licensed spectrum is still not used as much in frequency as in time, which means that traffic tends to be bursts, according to [3]. Joseph Mitola was one of the pioneers in this field. Their work, together with the spectral measurements of 1995 to verify the use of the spectrum in licensed bands, as well as those that are not licensed, served to initiate investigations in search of a technology that can mitigate the problem of saturation. spectral, using the spectrum efficiently [4].

B. *Radio Defined by Software*

One of the most significant evolutions in radio technologies has been the creation of the SDR, where the parameters of modulation, coding, demodulation etc., can be modified depending on the radio environment, all this by means of software [5]. Basically in [5] the concept of SDR is delivered as: “Radio in which some or all functions of the physical layer are defined by software”.

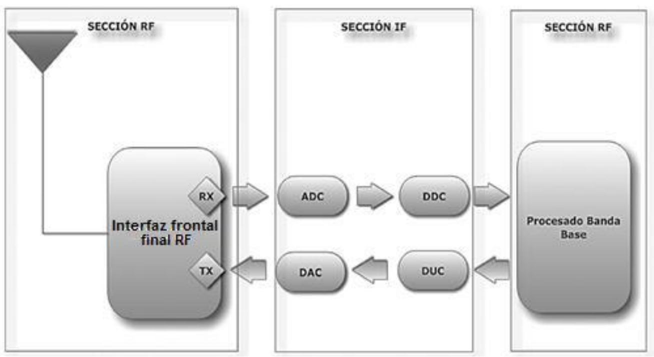

Fig. 1: Structure of a SDR

C. Concept of Cognitive Radio

There are several definitions for Cognitive Radio, all of them with similarity and relationship; but in essence all of them aim to achieve a correct use of the spectrum by means of cognitive abilities,

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in order to offer quality information to the user [3]. D. Main Characteristics of a CR Device Two main characteristics of CR devices are defined, taking into account the basis of the concept introduced by Joseph Mitola III in his doctoral thesis, these characteristics are [6]:

1) Cognitive Capacity: Interaction with the environment in real time, necessary to determine the free spaces and thus be able to adapt to the same environment, establishing the appropriate operating parameters [6].

2) Auto-reconfiguration: Capacity of CR to establish its parameters again or change them according to the requirements of the environment that will naturally be changing, this without modifying the hardware components; that is, it is only done through software [6].

E. Cognitive Cycle

1) Observation: In this phase, the radio environment is verified, that is, it constitutes the stage of detection, with which it is possible to locate those bands of the spectrum, property of the primary users, that are not being used at a certain moment in time. time [5].

2) Orientation: In this phase the free bands that have been detected are analyzed, which constitute the blank spaces that will be used for the transmissions by the secondary users. Furthermore, in this phase, the transmission parameters of the detected bands can be extracted [5].

3) Decision: After obtaining the results of the two previous phases, it will be necessary to make a comparison of all the available bands and decide which of them is the most appropriate for the transmission that must be carried out [5].

4) Action: In this phase the transmission is carried out; but because the radio environment is changing, that is to say that by the very nature of cognitive radio a primary user can appear at any time, which has a preference over the CR user, in this case he must be prepared to act in any moment, thus forming a cycle [5].

III. Spectrum Detection

As described above, the cognitive cycle comprises several stages, the first, which is fundamental, is the detection, since by means of it it is possible to know the existence of a primary user and whether or not it is transmitting.

A. *Methods for Detection*

The fundamental techniques are:

1) Energy detector: It is the detector mostly used, due to its low computational complexity. This forces you to make it less optimal by comparing it with others since it basically depends on a threshold. This type of detector is strengthened in the ability not to require in-depth knowledge of the primary user signal information [7].

The expression for the calculation of energy has the following form:

$$M = \sum_{1}^{N} |y(n)|^2 \qquad (1)$$

Likewise, two hypotheses are handled:

$$H_0 : y(n) = r(n) \qquad (2)$$

$$H_1 : y(n) = x(n) + r(n) \qquad (3)$$

And two probabilities:

$$P_D = P(M > \lambda | H_1) \qquad (4)$$

$$P_F = P(M > \lambda | H_0) \qquad (5)$$

Where:

PD: Probability of successful decision.

PF: Probability of false alarm

2) Detector by adapted filter: In [8] it is recognized as the optimal method, where the filter output is equivalent to the output of a correlation receiver. In this way it requires less time for detection, but it is very complex to require information of the signal to be detected.

3) Detector based on cycloestationarity: This method takes advantage of the periodic characteristics of modulated signals [8]. Different types of transmissions have different periodicities, while noise tends to be stationary, being a robust method before it.

IV. Design

By collecting information about energy detection, a block diagram has been proposed to be followed to achieve the design of the energy detector.

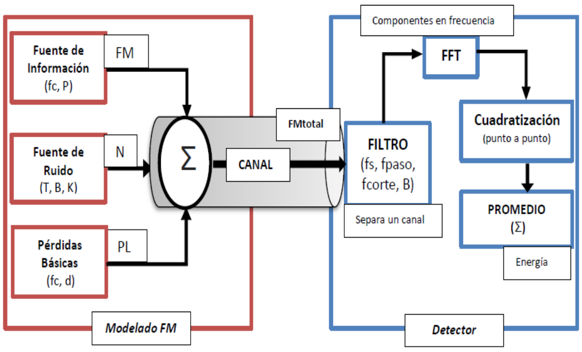

Fig. 2: Block diagram showing each step to follow prior to comparison with the threshold

A) Input Signals Bank

It should be taken into account that the present work is oriented to the band designated for FM broadcasting (88 - 108 MHz), therefore the signal bank is modeled based on mathematical expressions of frequency modulation.

Being only an energy detector, it is possible to dispense in this design the technical parameters with which each of the radio transmitters transmit their signals, it is enough to simulate a power of similar characteristics to those they generate in their operations.

Each signal has been modeled to comply with a power similar to that mentioned in article 31 of [9].

The results are shown below:

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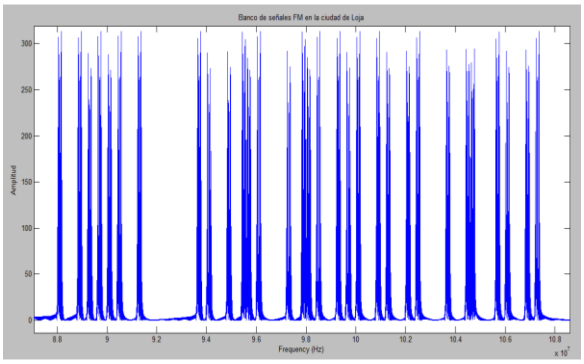

Fig. 3. Bank of 100 FM signals (31 active, according to information from the city of Loja).

But this is a complete signal, which does not resemble a real broadcasting environment, to achieve this, loss and noise factors are added, which is described below.

B. *Noise and Losses*

For the present design the basic parameters of noise and losses in radio transmissions are considered, these are the losses in free space, which depend both on frequency and distance, and the noise present in any system, such as thermal noise, which is combined with fortuitous values and thus obtain the random nature of it.

1) *Thermal Noise:* From [10] we have:

N = KTB (6)

N: Noise power (Watts).
B: Bandwidth (Hertz).
K: Boltzmann proportionality constant (1.38 X 10-23 J / ° K).
T: Absolute temperature in Kelvin (ambient, 290 ° K).

For the generation of noise, the entire FM bandwidth (20MHz) and an average temperature of 25 ° C have been taken into account.

2) *Basic losses:* From [11] the following expression of losses in free space is obtained:

$$PL\ (dB) = 32.45 + 20\log_{10}(f\ (MHz)) + 20\log_{10}(d(km))$$

f: central frequency of the input signal.
d: distance between TX and RX.

To choose the range of distances to be evaluated and to model, including the losses, we have taken as reference the hill Windows of the city of Loja and three sectors of possible location of the detector as more distant points:

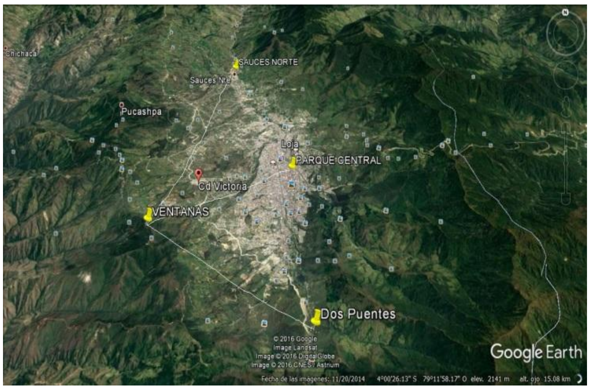

Fig. 4. Maximum distances to be taken into account for the evaluation within the urban center of the city of Loja.

- Ventanas – Sauces Norte: approximately 10Km.
- Ventanas – Dos Puentes: approximately 7Km.
- Ventanas – Parque Central: approximately 6Km.

Then you get:

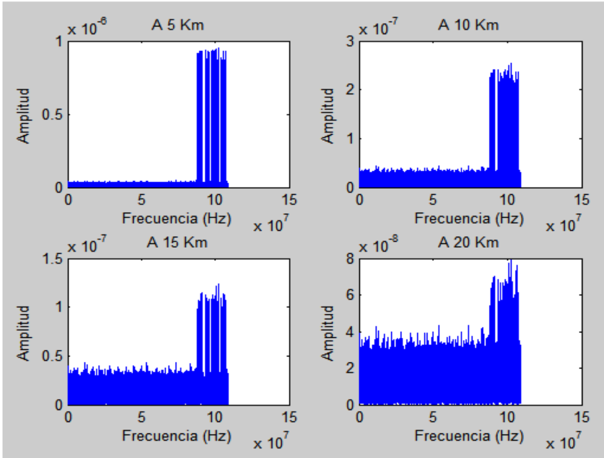

Fig. 5. Attenuation of the signal bank for the different distances.

The attenuation of the signals is evident and as the distance increases the noise level increases.

C. *Filtering*

Filtering becomes a complicated action within the design; The idea is to have a filter with the bandwidth of an FM channel (200KHz) that can slide, sweeping the entire FM band. The MATLAB - FDATool (Filter Design & Analysis Tool) tool is applied to design the filter, obtaining better results. The attenuations for both the pass band and the reject band are left in the default values of said tool, specifying only that it is a bandpass filter, based on Butterworth, the cutoff frequencies and the sampling frequency.

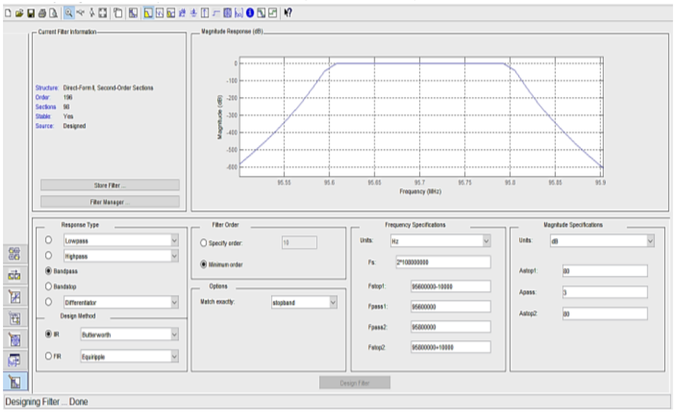

Fig. 6. GUI FDA Tool

To be able to "move" in frequency the filter in each iteration of a FOR loop, it has been necessary to enter the source code of the design thrown by the FDATool tool and extract it, to later append it to the present design on ENERGY DETECTOR. With the aforementioned, the variables used in said source code have been conserved with the same names in the present design; they are only adapted according to the needs that arise.

D. *FFT and Obtaining Energy*

Once a channel is separated, the transform is extracted, using the FFT algorithm of MATLAB, obtaining its components in frequency within a vector.

The following is to extract the present energy, by means of equation 1.

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With this we can obtain a power value that can be compared with the established threshold.

V. RESULTS

The results are mainly thrown in 2 matrices. The first matrix corresponds to the results of Power, this shows the energy level detected in each of the 100 FM channels at 5, 10, 15 and 20Km (matrix of 4 x 100). The second is the detection matrix, here a value of "1" is assigned when considering that a certain channel is occupied or a "0" if it is idle or free, all based on the power levels determined in matrix one. With these two matrices it can be shown graphically how the proposed design behaves.

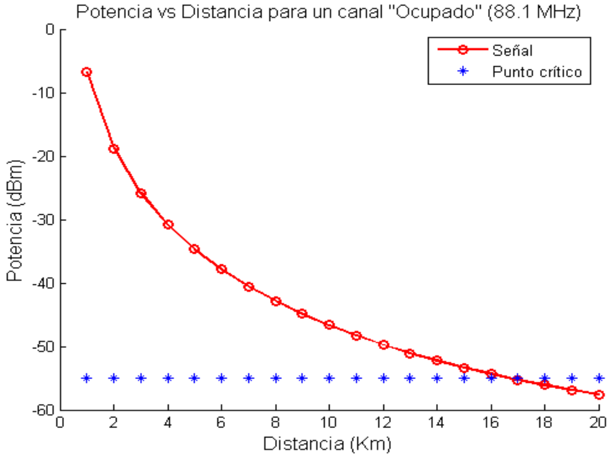

Fig. 7. Power variation for the channel "Luz y Vida FM" of the city of Loja, as the distance increases.

Figure 7 shows how the power detected in a given channel varies as the distance increases. A decreasing exponential curve is observed, this due to the loss of energy as the detector moves away from the transmitter.

The other channels show a similar variation, mainly due to the fact that each one has been modeled with a similar power.

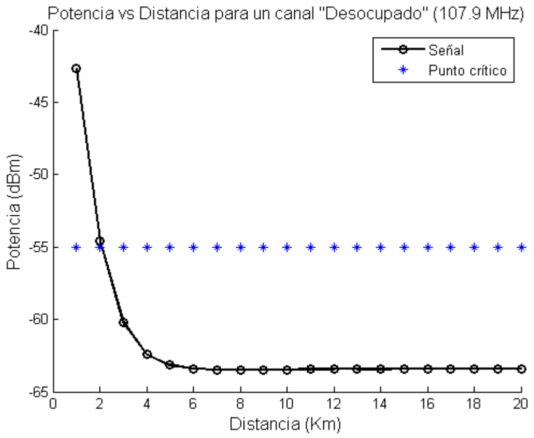

Fig. 8. Power variation obtained for an unoccupied channel at 107.9 MHz as distance increases.

Figure 8 shows the variation of power as the distance increases, when there is no FM signal present. It is observed that for almost the entire test range the signal is below the threshold, however modeling of the FM environment presents a high power level compared to the threshold for distances less than 5Km. Taking into account figures 7 and 8, the ideal working range presented by the design has been established, this is from 5Km to 15Km.

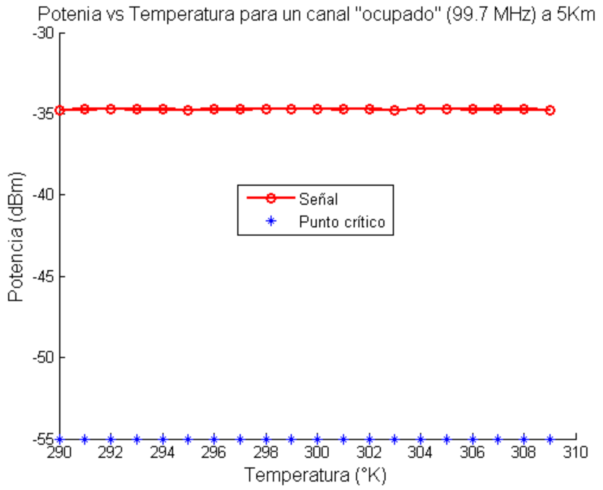

Fig. 9. Power variation for a channel occupied at 99.7 MHz at a fixed distance of 5 km and as the temperature increases.

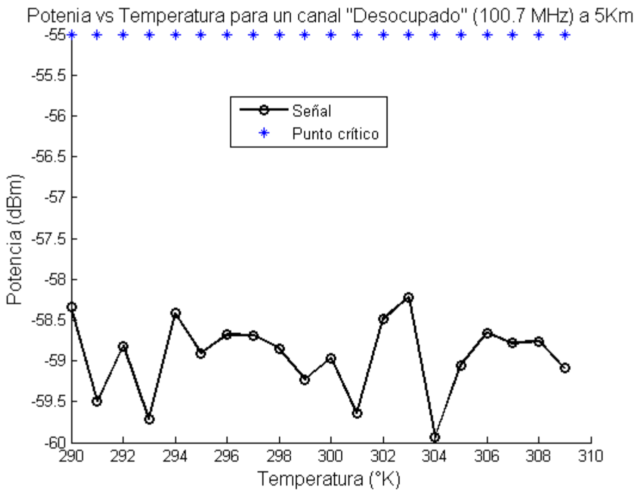

Fig. 10. Power variation for an unoccupied channel at 100.7 MHz at a fixed distance of 5 km and as the temperature increases.

Figures 9 and 10 show how the power varies as the temperature increases for a fixed distance of 5 km, for a busy channel and a free channel respectively.

As expected at this distance the signal variations are minimal and do not affect, because there is a level above the threshold.

When there is only noise, it is affected by temperature and presents abrupt variations; however its power is below the critical point.

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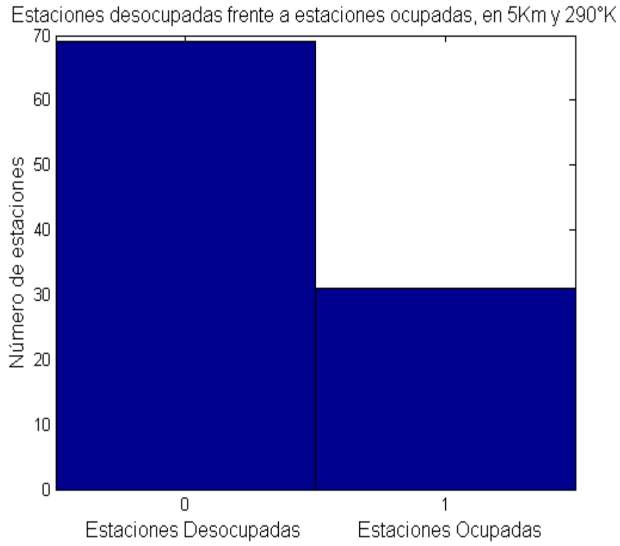

Fig. 11. Representative histogram on occupation results at a distance of 5 km and 290 ° K

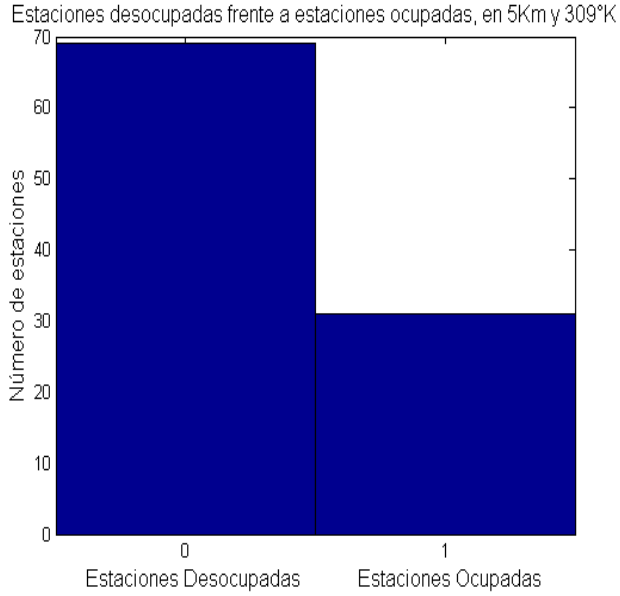

Fig. 12. Representative histogram of occupation results at a distance of 5 km and 309 ° K.

Figures 11 and 12 are histograms that are used to verify quickly if the proposed design detects the same number of active channels, as those entered according to the FM signal bank.

As can be seen, these two graphs (at 290 ° K and 309 ° K) show us that the design manages to detect 31 active stations, which is the same number used by the previously modeled signal bank.

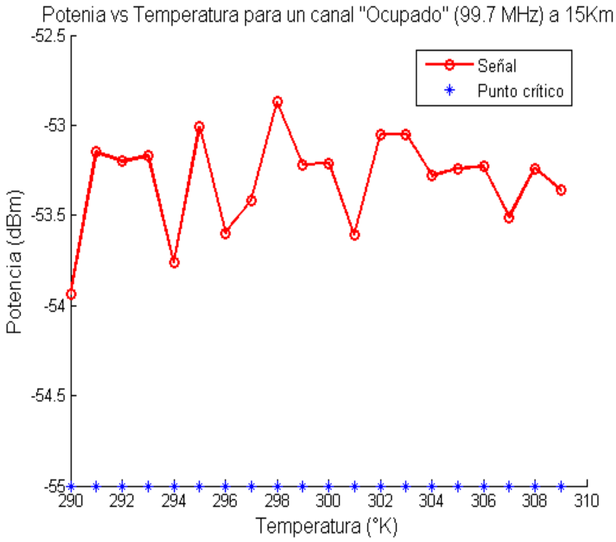

Fig. 13. Power variation for a channel occupied at 99.7 MHz at a fixed distance of 15 km, as the temperature increases.

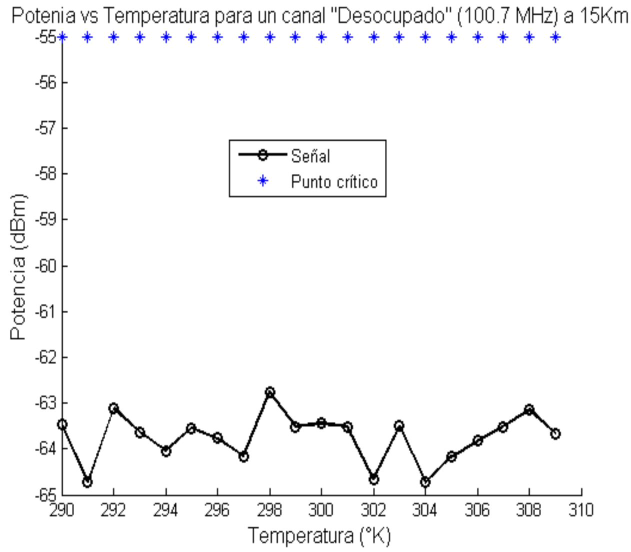

Figure 14 Power variation for an unoccupied channel at 100.7 MHz at a fixed distance of 15 km, as the temperature increases.

Figures 13 and 14 show the variations in power as the temperature increases for both a busy and an unoccupied channel, in this case at 15Km.

It can be seen that the variations are now more pronounced than at 5Km, however at this distance none of the points of these graphs that represent the power of a certain channel are below the threshold for the case of Figure 13, nor for above in the case of figure 14, obtaining the expected response.

Fig. 15. Representative histogram of occupation results at a distance of 15 km and 290 ° K.

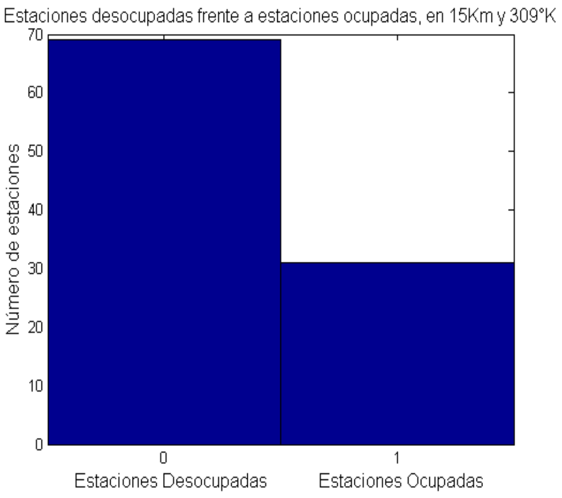

Fig. 16. Representative histogram of occupation results at a distance of 15 km and 309 ° K.

Figures 15 and 16 show two histograms, this time at 15Km, but it is observed that the design obtains the same results as at 5 km, which shows consistency of operation. SAW.

VI. CONCLUSION AND FUTURE WORK

A viable method of spectral occupation analysis results in the detection of energy, does not require complex technical information such as type of modulation of the signal or to establish adapted filter actions and cycloestationary characteristics of the radiated signals. Likewise, the analysis threshold in principle can represent a disadvantage due to the amount of energy propagated in the air interface at different levels and from different sources; Advantageously, the ARCOTEL regulations, which specify the minimum intensity that FM radio signals must present, limit the work and justify the laboratory analysis developed. On the other hand, mathematical analysis for the study of signal energy, losses and inherent noise is a priority where Matlab's FDATool and FFT tools become an indispensable complement for the correct performance of the system. Finally, the virtual evaluation of the design has been able to verify its validity and has allowed to determine an optimum range of work, which ranges from 5Km to 15Km, in which any signal that is above the established threshold will be detected, for the present work was operated with the value of -55dBm. It remains a broad challenge to take it to its implementation on a real electromagnetic radiation scenario.

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