TELEVISION ACTIVITY DETECTION:
A STATISTICAL-BASED
OPPORTUNISTIC SPECTRUM USE APPROACH

THESIS

PRESENTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN ELECTRONICS ENGINEERING
WITH MAJOR IN TELECOMMUNICATIONS

BY

EDWIN MERA AVILA

MONTERREY, N.L. JULY, 2009
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INSTITUTO TECNOLÓGICO Y DE ESTUDIOS SUPERIORES DE MONTERREY

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The members of the evaluation committee hereby recommend accepting the thesis presented by Edwin Mera Avila in partial fulfillment of the requirements for the degree of

Master of Science in Electronics Engineering with major in Telecommunications

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July 2009
To the Lion of Juda,

to whom I entirely belong.

Javeh Nissi, Javeh Jire, Javeh Shalom.

I thank Thee for the privilege of Thy Mercy,

   Grace, Endless Love and Eternal Legacy.
Abstract

The following thesis document develops a research proposal that can be thought of as an alternate Cognitive Radio method, designed for the detection of periodic patterns embedded on Analog Television Composite Video Signals. The method strives for reliable and efficient spectrum reutilization through the assertion of TV activity on any particular spectrum frequency.

In order to take advantage of the properties of Barker Codes autocorrelation functions, an expansion is proposed based on a pre-processing scheme using signal masking. Once it is masked, the baseband composite video signal will then be passed through a filter matched to a Barker Code-type pattern and a correlation spike will appear as an indicator whenever a valid pattern is found on the incoming signal.

The proposed technique will serve as a television activity detection tool and will be capable of operating conditions in noisy environments where the SNR may drop down to -20dB. It represents a low cost and high efficiency method to promote spectrum reutilization, as all secondary devices will have a reliable tool for spectrum sensing that will allow TV activity awareness before transmitting and causing harmful inband interference to licensed broadcasting stations/devices.

The following proposal to be developed provides useful contributions to the state-of-the-art developments on Cognitive Radio and TV activity detection as it:
• Guarantees the feasibility for the implementation of new wireless networks within areas that are already covered by other wireless service providers.
• Will be applicable to assess the presence/absence of analog television activity on the 700MHz frequency band, and will also be expandable to other spectrum allocations.
• Offers implementation flexibility as it can be applied to any wireless standard technology.
• Provides an objective criterion to support or disapprove decisions for projects in the wireless service market.
• Provides tools to improve spectrum utilization.

The designed technique is based on a simple idea and supported by decades of proven mathematical and statistical theories. For such reason, it represents a strong alternative for future field applications; besides, it provides further improvement areas that might be considered in future research works.
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To my dearest professor (in the British sense) of all, Dr. David Muñoz. Thank you for your patience and for the experiences shared inside and outside the classrooms. Being a part of your staff has been an enriching stage in my scholar and professional development. I look forward to keeping up the good work and learning more each day in order to be soon able to make a contribution to the State-of-the-Art in the Telecommunications field.
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To my second parents, Lucio and Elizabeth. Thanks for your prayers, your support, your parental love and spiritual guidance. Thank you for reminding me that there will always be a loving God who fights the battles in my stead.

To my Muse, my Walkyrie, my other self. Thank you for being close to me, for your unconditional and inexhaustible love.

Edwin Mera Avila
July, 2009
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Chapter 1

Introduction

For many years, the television has represented one of the most important inventions that marked the scientific, technological, political and mostly economic evolution in most societies throughout the world. As newer technologies emerged, the evolution of TV receivers became eminent, just as all other inventions in every other field of knowledge especially in electronics and telecommunications areas. Older b/w TV receivers are no longer comparable to today’s compact-sized LCD or plasma television screens, capable of full HDTV image display and complex image processing features.

However, despite all of the advancements in VLSI devices and data transmission protocols, the essence of television still remains as it was first conceived: a structured method to display steady images based on encoded signaling and a strict timing that forces the human eye to perceive continuous movement [1]. It does not matter if the technology claims to be analog or digital, from one standard or another; the basic working principle is the same.

It then turns out to be of enormous importance to study the forms and properties of both the signaling and timing involved in constructing the TV composite signal. Furthermore, spectrum allocations, bandwidths, modulation techniques, propagation and interference scenarios will also be helpful in the process of better understanding the operation of television receivers. Once having done so, it will be possible to propose relevant approaches dealing with the assertion of TV activity detection on a specific portion of the spectrum.
1.1 Synopsis

The United States of America has reallocated some television channels particularly those in what has been called “the 700MHz Band” (698MHz to 806MHz, channels 52 thru 69) [3]. The former action is a result of the auction led by the Federal Communications Commission (FCC) in the first quarter of 2008. After the FCC suggested, revised and approved the spectrum gap licensing, the US Congress approved a federal law for all full-power television broadcast stations to stop broadcasting in analog format and begin broadcasting only in digital format.

One of the main objectives for the digital television (DTV) transition (conversion to all-digital television broadcasting) is to free up frequencies for public safety communications (such as police, fire, and emergency rescue). In addition, according to the FCC, it has been analyzed and proposed that some of the freed up frequencies be used for advanced commercial wireless services for consumers after the DTV transition occurs. The new vacant spaces after moving the analog TV channels are referred to as “White Spaces” [2].

Following the TV technology transition that the US is performing, it is likely that some other countries throughout the globe (Canada and Mexico for instance) will also begin to free up spectral gaps in order to take advantage of the benefits offered by DTV while opening opportunities on the telecommunications industry market.

As it is expected, new questionings will arise on what the best technology would be for applications in wireless services after the transition occurs. Such change will bring along several implications dealing with the diverse impact areas that the television has on each society. However, only the technical portion of the analysis directly concerns to the scope and purpose of the present thesis work.
1.2 Problem Statement

Once the DTV transition takes place, those telecommunication companies that bid on and won a portion of the frequency spectrum will commence the deployment of the infrastructure required to provide wireless services.

It is important to distinguish between the unlicensed label that the FCC is giving to those new devices operating on the White Space spectrum frequencies, versus the licensed label given to all TV band devices (transmitters and receivers) still remaining after the transition.

According to the FCC’s Office of Engineering and Technology (OET) reports, the minimum signal level for any analog TV receivers to operate properly has been set to -116dBm [4]. One of the most important implications that such minimum threshold level brings up is that the maximum amount of tolerable inband activity that may prevail on a geographic area, where white spaces are being used by commercial wireless service providers, must not be greater or equal to the established -116dBm. This requirement has been thought in order to guarantee that the unlicensed operating devices do not harmfully interfere on the remaining licensed TV broadcasting stations.

Hence for scenarios such as the previously described, a new problem arises: how to identify the presence of Analog Television RF activity in a particular frequency band where vacant spectrum (White Spaces) will remain after the DTV transition?

The importance of RF activity detection lays on the fact that the new devices (unlicensed) are not allowed to interfere with any authorized broadcast transmissions (licensed). Unlicensed devices must be capable of actively sensing the environmental RF spectrum activity and then, after the necessary processing, discard the presence of Analog TV signaling activity before transmitting.
1.3 Motivation

The research material that will be developed throughout the present document is a result of a small portion of the state-of-the-art science that is currently being exposed on topics related to cognitive radios, white spaces, Wi-MAX, LTE, 4G, etc. The incipient ideas first came up as simple suggestions that, based on old well-established theories and laws, found a way to grow and become the cornerstone of the present thesis work.

In spite of all the controversies, time delays, technical disagreements, and all what has been involved in the give-and-take, the 700MHz band clearance topic is finally finding a stable path. The licensed full-power analog television services will be migrated to digital technology and their used spectrum will be reallocated. The remaining White Spaces will be carefully treated and as a result, innovative activity detection proposals (such as the present one) will come in handy and ready for its field application.

1.4 Research Proposal

The main purpose of this research document is to develop a method to identify and assess the presence of analog television RF activity in any particular frequency band, in the form of an opportunistic spectrum use procedure. The method will be focused and based on the regularities and periodicities which, by standard, are embedded in every analog TV transmission and that any analog TV receiver is capable of identifying and processing.

Though the analog television standards are numerous and diverse throughout the world, the essence of the signaling regularities prevail in all of them, as will latter be discussed. Hence, the proposed method stands valid for analog television standards and can be easily adapted with the minimal amount of changes.
CHAPTER 1. Introduction

The proposed method takes advantage of correlation properties of the well known Barker Codes by means of a signal pre-processing scheme using the baseband composite video signal.

The method analyzes the behaviour of the composite signal in the presence of noise due to the environmental conditions. As will be thoroughly discussed, the proposed method is effective even in some scenarios where the Signal-to-Noise Ratio (SNR) drops down to -20dB; case in which the reception performance is expected to be remarkably diminished.

The research proposal conveys useful contributions to the state-of-the-art developments on Cognitive Radio and TV activity detection areas as it:

- Guarantees the feasibility for the implementation of new wireless networks within areas that are already covered by other wireless service providers.
- Will be applicable to assess the presence/absence of analog television activity on the 700MHz frequency band, and will also be expandable to other spectrum allocations.
- Offers implementation flexibility as it can be applied to any wireless standard technology.
- Provides an objective criterion to support or disincline decisions for projects in the wireless service market.
- Provides tools to improve spectrum utilization.

1.5 Document Organization

The present thesis document is developed in six chapters. Chapter 2 includes an induction to the main topics, principles and theories that will become the foundations of the research proposal, such as: the composite video signal, Barker Codes and their autocorrelation properties, the matched filter concept, and a brief introduction to the Cognitive Radio concept and some of the research lines that are currently on development.

Chapter 3 contains the mathematical developments of a Statistical-based
method for activity detection which finds its supporting principles on the second order statistics of a shadowing stochastic process. The main discussion topic is centered on the Level Crossing Rate (LCR) and the Average Fade Duration (AFD) and their possible expansion to the spatial autocorrelation modeling for a distance-based shadowing process.

Chapter 4 discusses an innovative Cognitive Radio area and proposes a correlation-based approach for television signal assertion on any particular spectrum frequency. Chapter 5 shows the simulation results for the correlation-based tools proposed on the previous chapter and finally, Chapter 6 presents some of the problems on the area that still need further work to be developed by the future generations of researchers.
Chapter 2

Topic Backgrounder

In order to better understand the scope, purpose and goals of the proposed research work, it is important to lay out the main topics, principles and theories on which it is based. For such reason an induction is given to the cornerstone themes that constitute the foundations of the research proposal. Such topics include: television signal composition in the time domain (Composite Video Signal), Barker Codes and its autocorrelation properties, Matched Filter theory basics, and a brief introduction to the Cognitive Radio concept and the main research areas involved in its development.

2.1 The Composite Video Signal

A brief introduction is provided so that the composition of the television signals in the time domain is clearly understood. It is important to keep in mind that the scope will be on the regularities and periodicities that every standard must aggregate in the final composite signal for the receiver to be able to correctly “synchronize” the steady images sent by the transmitter.

Hence, the signaling and timing analysis will be mainly focused on the synchronization sequences described by analog television standards, such as: NTSC, PAL and SECAM.

The topics developed throughout this chapter are based on the book by Jack Keith [5] in its Chapter 8 entitled “NTSC, PAL, and SECAM Overview”. Further references are provided when different sources are used.
2.1.1 The Need for Sync Signals and Timing

Based on the principle of steady images superposition, the analog television as an invention found its applicability. It then became critical to find a way for the transmitter to tell the receiver when to begin drawing an image on the TV screen. And as a result, two key concepts were introduced: interlaced scanning and synchronization signals. Interlaced scanning is the method used to split the information of the frame in two fields: even and odd field. The even field is formed by all the even lines of the frame. Likewise, the odd lines form the odd field. The frame information is basically a sequence of the odd field followed by the even field and signaling in-between.

Such important signaling that is appended by standard is referred to as the synchronization (or simply sync) signals. The sync signals mark the beginning and the end of each line and each field. They tell the TV raster when to move down (vertical trace), up (vertical retrace), right (horizontal trace) or left (horizontal retrace). The sync signals (or pulses, as will later be shown) coordinate the movements of the beam deflector at the TV receiver so that the displayed image remains “steady” and centered at all times.

The following figure shows an example the interlaced scanning pattern followed by the NTSC standard (525 horizontal lines) [1].

![Interlaced Scanning Pattern for NTSC Standard](image-url)
During the interlaced scanning, the information sent for every image is halved. This means that the odd number lines are transmitted followed by the even number lines. Synchronization signaling is added at the end of each set of lines (odd/even fields).

### 2.1.2 TV Spectrum Usage

TV signals are generally transmitted using some type of amplitude modulation technique. For instance, the NTSC and PAL standards establish a Vestigial Side Band (VSB) modulation type for broadcasting purposes.

![Fig. 2.2 Spectrum Usage in a) NTSC and b) PAL Standard](image)

One of the differences between both standards is the spectrum usage. The NTSC channel occupies 6MHz while a PAL channel uses 8MHz. It seems obvious why the PAL standard channel is bigger, since the lines for each frame exceed by 100 to those described by the NTSC standard.
The color information is included in the upper part of the video spectrum and, for the NTSC standard, it is modulated using orthogonal (I & Q) components and a color (chrominance) subcarrier. The “luminance” signal occupies most of the available video spectrum as it contains information to which the human eye presents more sensitivity. After all, the human vision marks the guidelines on which the principles behind the television are based.

2.1.3 The Baseband Composite Video Signal

The Composite Video Signal in analog standards (NTSC, PAL or SECAM) is basically formed by the addition of the following components: the luminance signal, the modulated chrominance signals, horizontal and vertical sync signals, blanking information and color burst information.

The blanking information essentially draws “nothing” (blank) on the screen. The electron beam blanks two vertical sections, one at the beginning and the other at the end of each horizontal line. It is during the blanking periods that “extra” information can be appended to the video signal. The sync (horizontal and vertical) pulses and the color burst information are examples of this.

![Fig. 2.3 NTSC Composite Video Signal](image)
The color burst is the reference signal that helps the receiver to properly lock the phase (when the hue is modulated using phase difference) of the chrominance signal so that the hue is correctly displayed [6].

The composite video signal, in general, can be thought of as a signal containing the necessary information and timing needed to display steady images at rates that make the human eye perceive uninterrupted movement based on its intrinsic biological visual capabilities and limitations.

### 2.1.4 The Embedded Regularities: Sync Pulses

The sync information helps the receiver to know when a new image begins and hence, how it should be drawn on the TV screen. According to analog TV protocols, an over-the-air television signal must have synchronization fields added to the modulated chrominance signal. The main characteristic for such fields is their periodicity. There are two types of synchronization signals embedded on the composite video, namely:

- **Horizontal Sync**: Indicates when a new scan line is starting. The scan lines are basically lines of data that form the image sequentially.

- **Vertical Sync**: Indicates to the receiver when a new image is starting. It occurs every time a new field is to be drawn on the screen.

The sync pulses are added during the transmitter stage and their purpose on the receiver side is to keep the picture still and prevent it from rolling horizontally or vertically on the screen. The sync portion of the composite video signal may sometimes be used as the simplest way to encode a TV broadcasted signal. When the receiver does not notice the presence of synchronization pulses, the image will be rolling up or down and from one side to another. The only way to keep it steady is through the valid sync pulse sequences.

The following figure is an example of NTSC sync pulses [1]. It is important to remark that it shows the valid pulse widths for such analog standard.
A very important and exploitable condition of the sync pulses is their \textit{periodicity}. The TV receiver will always have to identify the sync signals to display the picture information. As a consequence, the embedded regularities will be available every time a valid video signal is present and ready to be decoded.

As can be inferred from the previous picture, the timing involved in every sync signal represents a critical component. The periods and forms must be strictly maintained for picture flickering avoidance.

A total of 30 sync pulses are present in each vertical synchrony stage in the NTSC standard: 6 Equalizing + 6 Vertical + 6 Equalizing + 12 Horizontal pulses. The purpose of the three existing types of sync pulses (Vertical, Horizontal and Equalizing) is to help the receiver identify and differentiate the duty cycle and
period of each pulse type in order to lock the proper timing needed for drawing
the images correctly on the TV screen, based on the redundancy of information
(reason to send several pulses instead of only one at a time).

For future thematic purposes the efforts will only be focused on the changing
sequence of Equalizing-Vertical-Equalizing pulses for all three analog standards. The
continuous 12-Horizontal pulse sequence within the vertical sync will be ignored as
its periodical properties are almost the same of every horizontal line that includes
video information. Thus, the NTSC standard includes a total of 18 alternating
sync pulses within the vertical sync stage.

As for the SECAM and PAL standards, the sync pulse sequences are formed
by only 15 pulses: 5 Equalizing + 5 Vertical + 5 Equalizing pulses. Even though
the timing is obviously not the same due to the frame display rates and number of
information lines for all three standards, the periodic properties can yet be
analyzed for any composite video signal by previously knowing the standard it
comes from.

Detailed picture information for the sync timing and periodic characteristics of
all three analog standards is provided in the Appendix A.1 section.

2.2 Barker Codes and Matched Filter Fundamentals

The Barker Codes (or sequences) are a particular family of binary phase codes
which are considered optimum as they produce compressed autocorrelation
waveforms with a function peak being equal to $N$ and constant sidelobes levels
equal to unity in magnitude (+1 or -1). The number $N$ represents the amount of
subpulses or elements in the sequence.

The Barker Codes found its nesting opportunity in radar theory, to which they
have been thoroughly applied, and have been the cornerstone of important
advancements on that particular area.
The main reason for the introduction of the Barker Codes in the present thesis work is because of their correlation properties. A Barker-type pre-processing for the composite video signal (particularly on the V-Sync sequence) will be proposed in further chapters and thus the theory of both Barker Codes and Matched Filter design must be carried along the next couple of sections.

The following developments regarding the Barker Codes and Matched Filter concepts are primarily based on the book by Herman J. Blinchikoff and Anatol I. Zverev [7] as well as the book by Bassem R. Mahafza and Atef Z. Elsherbeni [8].

2.2.1 The Known Barker Codes

There are only few binary codes that meet the desired compression ratio. Only seven known sequences meet such unique property. Unfortunately, there has not been found a Barker Code with over 13 components or elements. In addition, not all sequences exist for all $N$ less than 13 elements. The known sequences that meet the desired properties are presented in the following table:

<table>
<thead>
<tr>
<th>Barker Code Length $N$</th>
<th>Barker Code Elements</th>
<th>Peak-to-Sidelobe ratio $20\log N$ [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>+ , , + +</td>
<td>6.0</td>
</tr>
<tr>
<td>3</td>
<td>+ + -</td>
<td>9.5</td>
</tr>
<tr>
<td>4</td>
<td>+ + - , , + + + -</td>
<td>12.0</td>
</tr>
<tr>
<td>5</td>
<td>+ + + - +</td>
<td>14.0</td>
</tr>
<tr>
<td>7</td>
<td>+ + + - - + -</td>
<td>16.9</td>
</tr>
<tr>
<td>11</td>
<td>+ + + - - - - - + -</td>
<td>20.8</td>
</tr>
<tr>
<td>13</td>
<td>+ + + + + + - - + - + - +</td>
<td>22.3</td>
</tr>
</tbody>
</table>

2.2.2 Barker Code Autocorrelation Function

For thematic purposes, only the Barker Code of length 13 is analyzed. The autocorrelation properties for all seven codes can be found on the Appendix A.2 section.
The following figure shows the Barker Code with 13 components and its corresponding autocorrelation function. The component width is denoted as $\Delta \tau$ and the Barker Code length is $\tau'$.

![Fig. 2.5 Barker Code of length 13 and its Autocorrelation Function](image)

In most applications the Barker Code's autocorrelation function is expressed in a normalized manner for visualization purposes. It can be observed that the remarkable characteristic of such function is the diminished (compressed) amplitude of the sidelobes compared to the energy value (value adopted by the autocorrelation function in the origin).

### 2.2.3 The Matched Filter Concept

The autocorrelation properties of any signal, but particularly of the Barker Codes, can be linked to the Matched Filter ($MF$) concept. A MF has a unique characteristic of producing the maximum achievable instantaneous SNR at its output when a signal plus additive white noise (not necessarily Gaussian) is
present at the input. Matched filters are often referred to as *optimum filters* in the SNR sense.

It is desirable to take advantage of the Matched Filter's properties as well as the correlation characteristics involved in the Barker Codes theory, and apply their benefits *somehow* to the regularities of the composite video signals.

But before discussing the way in which both theories can be joined together along with the sync pulses, it is important to go over the results of applying the MF concept to the Barker Code sequences.

### 2.2.4 The Mathematical Description of a MF

According to Wozencraft and Jacobs [9], a "filter whose impulse response is a delayed, time-reversed version of a signal \( \varphi_j(t) \)" is said to be matched to \( \varphi_j(t) \). In mathematical notation, the matched filter \( h_j(t) \) can be expressed as:

\[
h_j(t) = \varphi_j(T-t)
\]  

(2.1)

It is imperative that the signal \( \varphi_j(t) \) vanishes for \( t > T \) in order that the matched filter be physically realizable. This means that \( h_j(t) \rightarrow 0 \) for \( t < 0 \).

### 2.2.5 MF and Barker Codes

Following the theory stated in [9], an *optimum receiver* will result when a filter is matched to a delayed, time-reversed version of a signal of interest. In a particular case, let such signal be the Barker Code of length 13 (L-13) from Table 2.1. The proposed MF to such code would be, according to Fig. 2.5 and Eq. (2.1):

![Fig. 2.6 a) Barker Code L13, b) MF to Barker Code L13](image)
Now let the following system be used to compute the output that results from the convolution of the signal of interest and its corresponding MF:

![Matched Filter Basic Block Diagram](image)

The output $y_j(t)$ can be computed using an extension of the multiplication method proposed in [7] as follows:

\[
\begin{align*}
\text{a) } & & 1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 & 1 & 1 & 1 & -1 & -1 & -1 & 1 \\
\text{b) } & \times & 1 & -1 & 1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1
\end{align*}
\]

Note: The signals a) and b) hold the same meaning as in Fig. 2.6

And now, after obtaining the autocorrelation signal as in Fig. 2.5, an important result has come up: a filter that was matched to a delayed, time-reversed version of the Barker L13 Code produced the autocorrelation of such code when it served as input to the system. In fact, any MF $h_j(t) = \varphi_j(T-t)$ will produce the autocorrelation of any $\varphi_j(t)$ whenever such $\varphi_j(t)$ is used as input.

With this important result obtained from the combination of both MF and Barker Code theories, the V-Sync pulse sequence is now ready to be analyzed and enhanced in search for a technique to assess or discard the presence of valid
television activity in any particular frequency band. The proposed technique is further developed throughout the following chapters.

2.3 The Cognitive Radio Concept

*Spectrum sensing* is a recently growing topic in wireless communication environments. Several approaches have been discussed and new proposals on the area appear rapidly. The imminent need for faster transmission data rates and higher quality communications has pushed the currently existing technology to an edge in which the spectrum re-utilization is becoming an implementation requirement. The next generation of radio communication devices will have to be capable of actively sensing the environment to *know* what type of activity is taking place on the location it needs to operate.

Just as in any development area, the wireless communication markets make use of a precious, limited natural resource: the radio electromagnetic spectrum. The Cognitive Radio arises as a novel technique capable of improving the utilization of such resource as an *opportunistic use - context awareness* approach. The proposed solutions deal with the spectral congestion problem by introducing an opportunistic usage of the frequency bands that are not heavily occupied by licensed users [10].

Though a formal definition for Cognitive Radio has not yet been agreed on the existing publications, the FCC’s approach can be used as a reference to identify the main idea and purpose that the concept embraces:

“*Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets.*” [11].
2.3.1 About *Spectrum Opportunity* Sensing

It is well known that the availability of the radio spectrum is limited and, as it is a natural resource, it must be licensed by governments to assure its proper utilization. However, the actual usage that is being given to the resource in most cases might seem notably inefficient (it is being underutilized).

The terminology in Cognitive Radio calls *primary users* to those devices operating on a certain area which have higher priority (or legacy rights) on the usage of a specific part of the spectrum. It also calls *secondary users* to those which have lower priority to make use of such part of the spectrum in a way that they are not allowed to cause interference to primary users. This is the main reason why secondary users need to have Cognitive Radio capabilities. Hence, sensing the spectrum for primary users’ activity is required so that the radio parameters of secondary devices are properly changed to take advantage of the unused part of the *spectrum opportunity* [12].

According to Kolodzy [13], a conventional definition of spectrum opportunity would be “a band of frequencies that are not being used by the primary user of that band at a particular time in a particular geographic area”. Spectrum sensing methods conventionally relate spectrum opportunity to such three dimensions (frequency, time and space).

2.3.2 About *Context Awareness*

Following Hykin’s more complete definition, some key concepts appear giving meaning to the cognition side of what a Cognitive Radio should be:

> “Cognitive radio is an *intelligent* wireless communication system that is *aware* of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to *learn* from the environment and *adapt* its internal states"
to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind:

- **highly reliable communications whenever and wherever needed;**
- **efficient utilization of the radio spectrum.**” [14].

The Cognitive Radio will then have abilities that will allow what is called the context awareness. This is, being aware of the radio channel characteristics and parameters regarding spectrum availability such as: power, radio’s operating environment, user requirements, available networks (infrastructures) and nodes, local policies and other operating restrictions [12].

Spectrum sensing is then the main task to be performed in order to obtain awareness about the spectrum usage as well as the presence of primary users in a geographical area. Several approaches have been proposed for this task. For instance, sensing can be performed by using geolocation and database, by using beacons, or by local spectrum sensing at cognitive radios as proposed in [15]–[17]. An important in-development research line according to Hykin, deals with the Cognitive Radio’s knowledge of the spatial distribution of spectrum holes (White Spaces) [14].

### 2.3.3 Cognitive Radio and Television Activity Detection

The current decisions in the matter of TV broadcasting technology in the US will inevitably promote the development of new alternatives for context awareness for spectrum frequencies in which the white spaces will remain.

The Cognitive Radio then appears as a feasible option for technology deployments and, for what it concerns to television activity detection, it seems to be an interesting solution due to the importance of the spectrum reutilization.
Chapter 3

Activity Detection - A Statistical Approach

The following sections show the developments for a White Space measuring and assertion procedure based on the Statistical Theory. It makes use of second order statistics as a way to compute the size of the possibly existing White Spaces around a particular transmitter.

The method’s main attempt is to respond to the following questions: what is the probability of a White Space existence on a particular geographical area? And, what is the maximum attainable size of such White Space?

It is inferred that the shadowing due to radio propagation on an urban environment follows a lognormal distribution, based on several empirical measurement results existing on the literature such as [18] and [19].

Before presenting the results for second order statistics, it is convenient to introduce some of the mathematical theory on which those are based.

3.1 The Lognormal Density

It has been empirically demonstrated that the received signal power of land-mobile radio signals, averaged over a distance scale of tens of wavelengths and expressed in decibels, tends toward Gaussian behaviour; hence, the term lognormal shadowing is applied. Let the lognormal density of a shadowing process be expressed as follows according to Hess’ notation in [20]:

\[
f_x(x) = \frac{1}{x\sqrt{2\pi\sigma^2}} e^{-\frac{[\ln(x) - m]^2}{2\sigma^2}}
\]  
(3.1)
Where $x$ is the value assumed by the lognormal random variable $X$, $m$ is the median value and $\sigma$ is the STD of the corresponding normal distribution, after the transformation $W = \ln(X)$. The variable IF is expressed in decibel [dB] units. It is desirable to calculate the probability density of $W$.

Applying the transformation $W = \ln(X)$ for a random variable $X$ which follows the distribution in Eq. (3.1), we have:

$$w = \ln(x)$$

$$\Rightarrow x = e^w = x_1, \quad \dot{w} = (1/x)$$

$$f_w(w) = \frac{f_x(x_1)}{|\dot{w}(x_1)|} = \frac{\left[\ln(x)\right]^{\infty}}{\sqrt{2\pi\sigma^2}} e^{\frac{[-\ln(x)]^2}{2\sigma^2}}$$

Hence, it is proven that the power expressed in decibels [IF] follows a normal (Gaussian) distribution.

### 3.2 The Time-Derivative of a Shadow Fading Process

Let $\psi(t)$ be a time-stationary stochastic process. For example, the signal power in decibels received at a distance $d$ from a radiating source. The time derivative (slope) of such a process can be calculated by the variation of $\psi$ in a differential time lap denoted as $\tau$. This is, according to Lee [21]:

$$\dot{\psi} = \frac{d\psi}{\tau}$$

Where $\tau$ is the time required for a change of ordinate $d\psi$. 
Let $\Psi$ be a specific signal level (or desired reference threshold). The parameters used for determining the slope and the physical interpretation of the second order statistics LCR (Level Crossing Rate) and AFD (Average Fade Duration) of the process $\psi(t)$, are shown in Fig. 3.1 & 3.2, respectively [21].

![Fig. 3.1. Physical Interpretation of the Time Derivative](image1)

![Fig. 3.2. Physical Interpretation of the LCR & AFD Statistics](image2)

It is important to remark that the positive slope gives meaning to the computation of the LCR and AFD as those are based on upward crossings in $\psi(t)$.

**LCR:**

$$N(\Psi = -7.5dB) = 4/T_{seg}$$

**AFD:**

$$\bar{t} = \frac{\sum_{i=1}^{N(\Psi)} t_i}{N(\Psi)}$$
3.3 The Joint Density $f(w, \dot{w})$

It has been proven in the literature that, if a given $w$ is a Gaussian Process, its time derivative $\dot{w}$ will also be a Gaussian Process [22]. Furthermore, both processes $w$ and $\dot{w}$ are uncorrelated in almost all cases [23]. The former statements make it possible to express both $w$ and $\dot{w}$ as mutually independent Gaussian processes [24], and hence, their joint density will have the form:

\[
    f_{w,\dot{w}}(w, \dot{w}) = \frac{1}{2\pi\sigma_1^2\sigma_2^2} e^{-\frac{(w-m_1)^2}{2\sigma_1^2} - \frac{(\dot{w}-m_2)^2}{2\sigma_2^2}} \tag{3.5}
\]

Since the expected number of positive (upward) crossings of any level equals the expected number of negative (downward) crossings, the average of the slopes $w$ should be zero ($m_2 = 0$), which will simplify Eq. (3.5) and leave it as:

\[
    f_{w,\dot{w}}(w, \dot{w}) = \frac{1}{2\pi\sigma_1^2\sigma_2^2} e^{-\frac{(w-m_1)^2}{2\sigma_1^2} - \frac{\dot{w}^2}{2\sigma_2^2}} \tag{3.6}
\]

It is important to remember that the units of $w$ are decibels [dB]. Now, the units will be converted from logarithmic to linear by means of a simple transformation as showed in the following section.

3.4 From $f(w, \dot{w})$ to $f(x, \dot{x})$

In order to maintain the linear (or nominal) notation in which the LCR & AFD statistics are expressed by the existing literature, it is desirable to reverse the levels from $w$ in decibels to $x$ in nominal units. As it is expected, the joint density of the nominal units will change. The following transformation equality is proposed for the calculation of such density:

\[
    f_{w,\dot{w}}(w, \dot{w}) = \frac{f_{x,\dot{x}}(x, \dot{x})}{|J|} \tag{3.7}
\]
Where \(|J|\) is the determinant of the Jacobian that relates both probability densities. Then, solving for \(f(x, \dot{x})\), Eq. (3.7) becomes:

\[
f_{x, \dot{x}}(x, \dot{x}) = |J| \cdot f_{w, \dot{w}}(w, \dot{w}) \tag{3.8}
\]

It follows from the transformation in Eq. (3.2), which was used to express the signal envelope in decibel units, that by using the chain rule, the time derivative of \(w\) can be expressed as: \(\dot{w} = (1/x)\dot{x}\). The determinant of the Jacobian that relates both densities can be calculated as follows:

\[
|J| = \begin{vmatrix}
\frac{\partial w}{\partial x} & \frac{\partial w}{\partial \dot{x}} \\
\frac{\partial \dot{w}}{\partial x} & \frac{\partial \dot{w}}{\partial \dot{x}}
\end{vmatrix} = \begin{vmatrix}
1 & 0 \\
\frac{x}{\dot{x}} & 1
\end{vmatrix} = -\frac{1}{x^2} \tag{3.9}
\]

And the new Joint density in nominal units will be:

\[
f_{x, \dot{x}}(x, \dot{x}) = \frac{1}{2\pi \sigma_x \sigma_{\dot{w}}} e^{-\frac{(ln(x)-\mu_x)^2 + (\dot{x}/x)^2}{2\sigma_x^2 + 2\sigma_{\dot{w}}^2}} \tag{3.10}
\]

The result in Eq. (3.10) will be the cornerstone that will allow the direct application of the developed formulas to compute the LCR and AFD statistics, as it is shown in the next section.

### 3.5 The LCR and AFD Expressions

Once the joint density in nominal units of the signal envelope \(x\) and its time derivative \(\dot{x}\) is found, the LCR and AFD second order statistics can be computed directly by following the expressions stated by Lee in [25]:

\[
LCR : N(x) = \int_0^\infty \dot{x} f_{x, \dot{x}}(X, \dot{X}) d\dot{x} \tag{3.11}
\]
### 3.6 Time-related Lognormal Process Statistics

The developed formulas would have a stronger meaning if they were applied to a specific problem. For instance, the application of the statistic expression in Eq. (3.15) requires temporal measurements. According to Marsan in [19], an
appropriate value for the lognormal shadowing standard deviation of $\sigma_1 = 5.5\text{dB}$ can be used for modest coverage sites, typical of cellular systems. The associate rate of change (time derivative) of shadowing, according to Hess [20], is on the order of $\alpha = 2.5\text{dB}$ per second for driving speeds typical of the local environment (i.e. 30mph in built-up areas and 55mph in more-open areas). Thus, from such data, the median LCR can be computed as:

$$N(x) = N(\ln(x) = m_1) = \frac{1}{2\pi} \left( \frac{2.5}{5.5} \right)^{\frac{(\sigma_1)^2}{2\sigma_1^2}} = 0.07234 \text{Cross, per sec.}$$

The crossing rate at one-sigma ($1\sigma$) fade level can be computed as:

$$N(\ln(x) - m_1 = \sigma_1) = \frac{1}{2\pi} \left( \frac{\sigma_1}{\sigma_1} \right)^{\frac{(\sigma_1)^2}{2\sigma_1^2}} e^{-\frac{1}{2}} = \frac{1}{2\pi} \left( \frac{2.5}{5.5} \right)^{\frac{1}{2}} = 0.0439 \text{Cross, per sec.}$$

And the Average Fade Duration (AFD) at such fade level ($1\sigma$) can be computed using Eq. (3.12) as:

$$\overline{t}(\psi = \Psi) = \frac{P_x(\psi < \Psi)}{N(\psi = \Psi) - N(\ln(x) - m_1 = \sigma_1)} = \frac{CDF_\psi(z = -1)}{N(\ln(x) - m_1 = \sigma_1)}$$

Where $CDF_\psi$ is the Standard Gaussian cumulative distribution function. In this particular case, the AFD can then be computed as:

$$\overline{t}(\psi = \Psi) = \frac{1}{2} \left[ 1 + \text{erf} \left( \frac{z}{\sqrt{2}} \right) \right], \text{ where } z = \frac{w - m_1}{\sigma_1} = -1$$

Thus:

$$\overline{t}(\psi = \Psi) = \frac{0.1578}{0.0439} = 3.614 \text{sec.}$$
Note: The units for both LCR and AFD for the time-related lognormal process are defined by $\sigma_1$ and $\sigma_2$ as follows:

$$[LCR] = \left[ \frac{\sigma_2}{\sigma_1} \right] > \frac{dB/sec}{dB} = \left[ \frac{1}{sec} \right]$$

$$[AFD] = \left[ \frac{\sigma_2}{\sigma_1} \right]^{-1} -> sec.$$

3.7 Applicability

The Statistical approach presented above follows the rules of probability distribution of lognormal shadowing. It is based on empirical measurements and depends on environmental conditions in order to provide accurate results. By means of mathematical derivations, both LCR and AFD statistics can be calculated if a distribution other than lognormal is needed.

The presented mathematical model can respond to the first target question "what is the probability of a White Space existence on a particular geographical area?", based on the signal level conditions and its cumulative distribution function. However, it is limited when it is necessary to provide an answer to "what is the maximum attainable size of such White Space?".

In such case, it is imperative to make a mapping from a time-based scheme to a distance-based scenario.

3.8 Improvements

The proposed statistical method could be further exploited if it is expanded to non-Gaussian distributions; for instance, an expansion to a scenario that may include the effects of short scale fading such as the Rayleigh or Ricean distribution. The mathematics needed to do such expansion may be quite difficult and time-consuming, but an accurate simulation model can be obtained along the process. An expansion to Rayleigh distribution density is provided by Lee in [21].
Chapter 4

TV Activity Assertion – A Correlation-based Approach

An alternate approach for analog television activity recognition and assertion is provided. It can be applied to all analog standards that have embedded periodic synchronization sequences (pulses) as a requirement, namely: NTSC (ATSC), PAL and SECAM.

For illustrative purposes only, the following method will be thoroughly applied to the American standard NTSC. The proposed variations of the technique needed for PAL and SECAM standards will be discussed once the general idea is clearly exposed.

The proposed method makes use of the previously discussed topics on sync signals, Barker Codes, matched filters and correlation functions. Furthermore, the method hereby presented shows a straightforward path for a secondary device to acquire cognition and context awareness on analog television signals from its operating environment.

4.1 Method Basics

This second alternate Cognitive Radio approach will be based on regular pattern detection in order to allow the assertion of analog television activity on a particular environment, in which the radio activity might be polluted with inband signals different than those emitted by a licensed TV broadcasting station/device.

The method will take advantage of the regularities embedded on the television signals to provide indicators that will lead to the assertion or discarding of valid TV signaling present on a particular scenario.
Those indicators will be basically signal spikes out of a carefully designed matched filter that will correspond to a specific part of the sync sequence. The signal spikes will help with the recognition of a valid television signal on the environment once they are properly processed. Further details are presented on the following sections of this chapter.

It is important to recall that the basic composition of the sync sequences in analog standards is primarily formed by two types of sync pulses: equalizing and vertical. The main difference between both types of pulses is the duty cycle as shown in Fig. 2.4 for the American Analog standard NTSC.

Depending on the pulse polarity (positive/negative), the positive duty cycle of the equalizing pulses will be of 4% of an H line, whereas for the vertical pulses the duty cycle is of 43% of an H line. Hence, an important consideration is that the vertical pulses will carry more energy than the equalizing ones.

### 4.2 A Filter Matched to the V-Sync Sequence

The first approach for taking advantage of the regularities in the TV signal deals with the whole V-Sync Sequence. Such sequence is formed by (remembering Sect. 2.1.4) a total of 18 alternating sync pulses (Equalizing-Vertical-Equalizing) plus 12 horizontal pulses in the case of the American standard.

A filter is designed so that it is matched to the complete V-Sync Sequence and then it is labeled as MF1. It is desirable to observe the behaviour of its output when the input is the complete V-Sync Sequence. According to Sect. 2.2.5, the expected output shall be equal to the autocorrelation function of such sequence. The scope is to rescue some useful correlation properties, if there are any.

Once the V-Sync Sequence is passed through the matched filter, the output shall show indicators that might be used for further processing that will lead to the assertion or discarding of a valid pattern embedded on the signal of interest.
CHAPTER 4. TV Activity Assertion – A Correlation-based Approach

The following figure shows the first attempt to analyze the periodicities in three steps: the V-Sync Sequence that serves as input, the Matched Filter design and its corresponding output respectively.

It can be observed that $MF_1$ is a time-reversed delayed version of the input signal, as expected according to the definition of what a Matched Filter should be (as in Sect. 2.2.4). The output however, shows no further use as the secondary spikes (other than the autocorrelation value in $t = 0$) or sidelobes are considerably large compared to the main lobe.

At this point, before enhancing the idea proposed in this first attempt, it is important to remember that, to be a good indicator of a valid pattern within an input signal, the desired matched filter output should have a large central spike and considerably small sidelobes (i.e. a signal obtained with the Barker Code’s autocorrelation function as in Fig. 2.5).
4.3 A Sub-sequence within the V-Sync Sequence

The behaviour of the autocorrelation function in Fig. 4.1c shows the presence of undesirable repetitive patterns that generate periodic spikes on the output sequence. A masking pre-processing is proposed for the elimination of such patterns. This means that the 12 horizontal pulses will be discarded, assuming that a blanking mask has been passed through them at the input stage of the filter.

The remaining portion of the V-Sync Sequence is then used to design a matched filter which will be labeled as $MF_{1a}$. The resulting autocorrelation for the 18 alternating pulses, as well as the input signal and matched filter design is shown on the next figure:

![Fig. 4.2 a) 18 Alternating Sync Pulses, b) $MF_{1a}$, c) Alternating Pulses Normalized Autocorrelation](image)

Though the observed autocorrelation profile is in a sense, better than that of the complete V-Sync Pulse Sequence, the sidelobes spikes are still large enough as to produce incorrect measurements while being treated as valid pattern indicators.
For such reason, a better input signal that does not produce large sidelobes is required.

The quest for a best sub-sequence within the V-Sync Pulse Sequence can lead efforts towards interesting intelligent algorithm topics. Based on a specified criterion or previously agreed set of rules, (i.e. best SNR, smallest secondary sidelobes, largest energy, etc., or even combinations of them), the best sub-sequence can be found based on the operating principles of all the existing applicable algorithms.

As such quest is in part out of the scope of this thesis work, the resulting best sub-sequence is provided given that it meets the following two main conditions:

- It is aperiodic within the complete V-Sync Sequence, granting better autocorrelation behaviour.
- It includes the largest pulses, providing enough energy to work with.

Fig. 4.3 a) Best Sub-sequence, b) $MF_2$, c) Best Sub-sequence Normalized Autocorrelation

Following the same idea, a third matched filter (labeled $MF_2$) is designed and
its output analyzed. The input signal, matched filter and output are as in Fig. 4.3.

The autocorrelation profile for the complete V-Sync Sequence is compared to and contrasted with the profile for the best sub-sequence in the following figure:

![Fig. 4.4 Autocorrelation Profile Comparison](image)

The improvement on the autocorrelation profile from one matched filter to another is considerably better as it shows smaller sidelobes and the main spike can be used for further processing as valid pattern indicator.

Before going any further with the proposed idea, it is convenient to lay out the main steps that were followed to design all of the matched filters that allowed the autocorrelation profile analysis:

a) Locate and describe the V-Sync Pulse Sequence in the time domain.
b) Find a particular sequence of pulses (within the Vertical Sync Pulse Sequence) for which its Autocorrelation is best.
c) Design a Matched Filter to that particular sequence.
d) Convolve the designed MF with the original Vertical Sync Pulse Sequence; observe and describe the behaviour of the expected output.
So far, two out of the three designed matched filters can be catalogued as useful for valid pattern indication: the first one ($MF_1$) matched to the complete $V$-Sync Pulse Sequence and the third one ($MF_2$) matched to the best sub-sequence. Though the autocorrelation in the first filter is not the desirable profile, it will serve as a guide for comparison purposes.

### 4.4 A Barker-type Pre-processing Scheme

The redundancy in the Equalizing-Vertical-Equalizing 18-pulse sequence (every pulse type is repeated 6 times) makes it difficult to obtain a desirable output signal having a large mainlobe within highly compressed sidelobes, as the ones obtained with the Barker Codes autocorrelation functions. However, the theory that applies to Barker Codes could also be applicable to the alternating pulse sequence.

As it was presented in Sect. 2.2.1, the largest known Barker Code has length 13. Taking advantage of the 18 pulses in the alternating sequence, a pseudo Barker Code can be obtained by means of a Barker-type pre-processing scheme. The input signal (in this case, the V-Sync Pulse Sequence or a masked variation of itself) could have the component profile that the Barker-L13 Code has. But prior to working on the input signal to obtain such correlation properties, a couple of important considerations must be properly followed:

- The **energy** of the input signal must be maximized in search for a better autocorrelation profile.
- The component profile must stay intact: $-+|++|--|+-|++|--|++."

As a limitation of a maximum length of 13 components for the input signal prevails, a set containing a total of six possible combinations are to be analyzed for the matched filter design process. Such sequences should include the six Vertical pulses from the 18-pulse alternating sequence so that input signal energy is maximized and hence, the above criteria that the method requires are met.
The following figure shows the possible six alternatives for the new input using 13 pulses out of the 18-pulse alternating sequence. By using any of such schemes, the energy is being maximized and also the coefficient/component profile is kept intact following the Barker L-13 Code.

![Fig. 4.5 Six Barker Pre-processed Inputs](image)

At first glance it is difficult to decide which one of the six pre-processed inputs would be the best. For such reason, a third criterion dealing with the autocorrelation profile is introduced. A matched filter is designed for input discrimination purposes on all of the six possible choices and its output is observed. In view of the importance to meet all the criteria as well as making the best choice while discriminating inputs, an improvement to the previously followed method for matched filter design is made: the input will experience real-type conditions when Additive White Gaussian Noise (AWGN) at several Signal-to-Noise Ratios (SNR) is also introduced as an input to the system. The following
figure shows the new system scheme to be used. The AWGN is labeled as $n_j(t)$ to keep previous notation:

![Fig. 4.6 Improved Matched Filter System Diagram](image)

The correlation profile analysis showed that the first input option (Fig. 4.5a) has the best attributes to meet the established criteria. The next figure shows such profile. The rest of the correlation analysis can be found on the Appendix A.3 section of the present thesis work.

![Fig. 4.7 Best Input Autocorrelation Profile Analysis](image)

It can be observed on Fig. 4.7 that the correlation profile is good enough as to support SNR of up to -20dB. As a result, a new useful filter will be designed based on the first input signal as shown on Fig. 4.5a. Such filter, for notation purposes, will be labeled as $MF_3$. 
4.5 About the **Masking** Process

The input signals in Fig. 4.5 were obtained by means of a **masking** process of the composite video signal. All Barker Coefficients (series of +1/-1 according to the L13 code) were utilized sequentially on the V-Sync sequence part of the video signal. The rest of the signal was blanked because the remaining portions of each mask are set to zero (blank level).

Each mask is basically a pulse of amplitude +1/-1 (depending on the Barker Coefficient) and width equal to one half of a horizontal pulse ($H/2$ is equal to the pulse width of every **Equalizing** or **Vertical** pulse), that multiplies the whole incoming composite video signal. The result of the sequential masking process is a **Barker-type pre-processed** sync sequence that will have an autocorrelation profile that takes advantage of the Barker Code correlation properties.
The following figure is a block diagram of the Barker pre-processing system:

![Barker-type Pre-processing System Block Diagram](image)

**Fig. 4.9 Barker-type Pre-processing System Block Diagram**

### 4.6 The Desired Barker Code Autocorrelation Profile

As a final goal, the desirable ideal processed input should look like a Barker L-13 Code. However, as it can be observed on the processed input sequences in Fig. 4.5, the Barker components are not complete. This is because both the Equalizing and Vertical pulses do not have a 100% positive duty cycle as to produce a perfect Barker-type autocorrelation.

The problem of completing a 13-pulse length pre-processed sequence based on the alternating 18-pulse sequence can be handled in numerous ways. The proposed idea to accomplish a full-sized Barker L-13 Code is as follows:

- Generate a sequence of delayed masks for all of the pulse sequence (the new versions of the mask will be called micro mask). The delays must be enough as to complete all Barker Code components.
- Multiply each micro mask by the incoming signal.
- Add the resulting delayed pulses to complete the Barker L-13 Code.

The following figure represents a graphical version of the proposed steps for component completion based on micro mask multiplication. Only one Barker Code component is shown for simplicity.
Based on the completed 13-pulse sequence and assuming that by means of the masking process the Barker L-13 Code is obtained, a new matched filter will be proposed. The final filter will be matched to the complete Barker L-13 Code and labeled as \( MF_4 \). Its output autocorrelation profile will be that of the Barker L-13 Code when it is used as input.

The quest for a Barker-type autocorrelation profile has now taken a new meaning given by the properties of such codes. The proposed masking process will make more sense when the complete composite video signal is analyzed.

The simulations proposed on the following chapter deal with the whole TV signal (luminance + chrominance + sync pulses) and, for performance analysis purposes, AWGN is also considered at several SNR.

Though the American Analog standard is the only one that has been proven on the simulator, the results will show that the method stands valid for all other analog standards. The needed modifications and other considerations are dealt with on the final section of the current chapter.
4.7 The Proposed Matched Filters

A total of four matched filters have been labeled as useful along the whole design process. The following figure contains such filters according to the signals that each has been matched to, namely:

- \( MF_1 \): matched to the complete V-Sync Sequence (incl. \( H \)-pulses).
- \( MF_2 \): matched to best subsequence within the V-Sync sequence.
- \( MF_3 \): matched to a Barker-type pre-processed section of 13 out of the 18 alternating pulses in the sync sequence.
- \( MF_4 \): matched to a complete Barker L-13 Code.

Fig. 4.11 Comparison of all the Proposed Matched Filters

The following chapter will show the results of the correlation-based proposal for TV activity detection. At this point, the basic idea of the matched filter design has been laid out. The following section contains a few considerations needed for the method to be applied to other analog standards (PAL/SECAM).
4.8 Additional Considerations

According to the following figure extracted from the book in [5], the vertical sync sequence in the PAL standard is formed by a sequence of only 15 alternating Equalizing-Vertical-Equalizing pulses. However, as it was proposed in Sect. 4.4, for the Barker Code autocorrelation properties to apply, some criteria must be met.

The good news is: the alternating sequence is long enough as to provide a combination of 13 pulses to generate a Barker-type pre-processed input signal. The only drawback is that a new analysis of all the possible combinations must be made in order to obtain a correlation profile that matches the remaining requirements regarding the component profile and the sidelobe compression compared to the mainlobe amplitude. Such correlation profile analysis is left for further attempts to improve the current research proposal.

![Fig. 4.12 PAL Synchronization Sequence](image)

Just as in PAL standard, the modifications needed for SECAM or any other NTSC/PAL/SECAM versions (such as interlaced or any other standard type) are minimal and in general are limited to a 13-length Barker Code completion and autocorrelation profile analysis as the one performed in Sect. 4.4 of this work.
Chapter 5

Simulation Results

Once the Matched Filters have been properly designed to allow the TV activity detection, they must be tested for performance. This chapter is fully dedicated to the analysis of each filter’s outputs when the inputs are several versions of the composite video signal at different Signal-to-Noise Ratios.

The four proposed Matched Filters will have input signals according to what they were designed to match. In the first place, the filter will receive two consecutive patterns to which the filter has been matched. In this case, the expected output will be the pattern's autocorrelation, according to the theory explained in Sect. 2.2.5.

The second type of input that the filter will receive is the pattern it has been matched to but this time it is embedded on the complete baseband composite video signal. It is expected that the output be the optimum in the SNR sense. In this as well as the previous case with the pattern alone, the input signal will suffer the impact of the Additive White Gaussian Noise.

5.1 The Filters’ Inputs

The following figure shows the inputs to all of the four matched filters. The inputs’ description is respectively:

a. Complete V-Sync Sequence (18 alternating + 12 Horizontal pulses).
b. Complete V-Sync Sequence within the Composite Video Signal.
c. Best correlation sub-sequence (6 Vertical pulses + 2 Equalizing each side).
d. Best correlation sub-sequence within the Composite Video Signal.
e. Barker-type pre-processed input signal.
f. Barker-type pre-processed input signal within the Composite Video Signal.

g. Barker L-13 Code (full pulse width).

h. Barker L-13 Code within the Composite Video Signal.

Fig. 5.1 Inputs to all four Matched Filters
5.2 $MF_1$ Outputs

The next set of outputs belongs to the corresponding inputs in Fig. 5.1a and 5.1b.
The first five outputs in Fig. 5.2 (a thru e) are the result of modified versions of the input in 5.1a at several SNR. Likewise, the rest of the outputs (f thru j) correspond to modified versions of the input in 5.1b also at several SNR.

This means that both the first and the second inputs were introduced to $MF_i$ simulating five different SNR, namely: $\infty$, 0dB, -10dB, -20dB and -30dB. The first set of outputs shows the autocorrelation profile for the whole V-Sync Sequence repeated twice along the observed time window. It is important to remember that a complete TV frame (odd field followed by even field) contains two vertical sync sequences and for such reason, the two profiles appear on the filter’s output. The symmetry, which is also a characteristic of the autocorrelation function, is well defined on each of the resulting peaks out of $MF_i$.

The second set of outputs on the other hand, shows irregularities on the symmetry with respect to the signal peak. This is due to the variations on the input signal polarity. According to the standard (NTSC), the polarity of the synchronization pulses must be the opposite of the video information signal in order to prevent the sync information to be interpreted as video information by the receiver. Though the composite video signal includes both types of information, the sync sequences might be thought of as blacker than black. This happens because their level is still lower than the blanking threshold and thus, they may not represent any valid video information.

The $MF_i$ filter represents only a first approach to take advantage of the composite video signal regularities. Just as the inputs/outputs were described for better understanding of the process being followed, the forthcoming analysis shall be done the same way for the remaining three matched filters.

All the resulting outputs will be placed on the following sections and the filters’ performance will be analyzed at the final section of this chapter. The order and notation used so far will be kept for congruence.
5.3 $MF_2$ Outputs

The next set of outputs belongs to the corresponding inputs in Fig. 5.1c and 5.1d.
5.4 $MF_3$ Outputs

The next set of outputs belongs to the corresponding inputs in Fig. 5.1e and 5.1f.

![Fig. 5.4 Matched Filter 3 Outputs](image-url)
5.5 $MF_4$ Outputs

The next set of outputs belongs to the corresponding inputs in Fig. 5.1g and 5.1h.

![Normalized Matched Filter 4 Outputs](image-url)
5.6 Matched Filters Performance Analysis

Looking at the previous plots, the response of the designed matched filters for television pattern recognition improved from \( MF_1 \) to \( MF_4 \). The reference filter \( MF_1 \) shows a small tolerance to noisy environments and as activity indicator is unreliable, even at high SNR (> 0dB). The resulting amplitudes of the sidelobes make it difficult to assess the presence of a sync pattern spike indicator.

On the other hand, the filter \( MF_2 \) based on the best sub-sequence shows a notable improvement on the output’s SNR. The noise level out of the filter is remarkably diminished. However, as the best sub-sequence is in part a fragment of the complete V-Sync Sequence, it is easily perceived how the correlation properties were also inherited as the sidelobe amplitudes would make it difficult to identify a peak that would assess the presence of a valid pattern when the SNR is poor (< -10dB). The use of \( MF_2 \) is recommended only for cases when the SNR is over 0dB and if the available resources would make it impossible to process the incoming composite video signal, as it is the case of the following filter.

The proposed \( MF_3 \) requires that the signal be pre-processed accordingly. The masking process has been detailed on Sect. 4.5. When compared to the previous two filters, \( MF_3 \) has a clear advantage but also a considerable drawback. The output’s main spikes are extremely sharp and the sidelobes amplitudes are remarkably compressed. Nevertheless, the noise floor is at critical values for SNR below -15dB and the peak assertion for pattern validation might be compromised. Even though the use of \( MF_3 \) will require some previous processing, the output’s performance is far better that the former \( MF_1 \) and \( MF_2 \).

\( MF_4 \) may be considered as the ultimate goal on the television pattern assertion process. Although it requires the Barker L-13 Code to be completely embedded on the composite video signal, the response is optimum for SNR as low as -20dB.
As it was previously stated, the *ideal* autocorrelation profile should have a large signal compression. This means that the ratio between the maximum value (when $t = 0$) of the processed (or not) input's autocorrelation function ($R_{xx}(t)$) and the largest amplitude of the sidelobes, should be maximized.

In order to find an objective criterion to discriminate among the proposed Matched Filters, the **Peak-to-Sidelobe Ratio (PSR)** will be introduced. The PSR will be defined following the notation below:

\[
PSR = 20 \log_{10} \left( \frac{R_{xx}(t = 0)}{\text{MAX}[\text{sidelobes}]} \right)
\]  
(5.1)

Where $R_{xx}(t = 0)$ is the input's autocorrelation value at $t = 0$ and \text{MAX}[\text{sidelobes}] represents the largest sidelobe amplitude as shown by the following figure as dotted line. The autocorrelation profiles correspond to the inputs used to design the proposed four Matched Filters.

![Fig. 5.6 Largest Sidelobe Amplitude](image-url)
The four inputs were treated at four different SNR, namely: $\infty$ (noiseless), 0dB, -10dB and -20dB. The signal compression was computed using the correlation profile and the PSR formula in Eq. (5.1); the observations were averaged over 100 samples each time. The resulting PSR is then an estimation of the Mean Signal Compression as shown by the following figure.

![Matched Filters Performance](image)

Fig. 5.7 Matched Filters Performance Comparison

It can be observed that the proposed $MF_3$, based on the Barker-type masking and preprocessing scheme, has a bigger compression than the first two filters which are only based on the incoming V-Sync Pulse Sequence. The $SNR$-optimum (ideal) output correlation profile is obtained by embedding the complete Barker L-13 Code on the input signal and passing through the $MF_4$.

The obtained curves in Fig. 5.7 show the improvements on the output profile attainable by the proposed scheme. Further comments and complementing research areas are proposed in the next chapter.
Chapter 6

Conclusions and Further Work

All concepts seen so far represent a junction of both antique well-established and novel in-development theories; when put together they constitute the pillars on which the proposed television activity detection method is based. Though the validity of the technique is proven along the document development, the research problem dealt with brings up other possible working scenarios that need to be further analyzed in the near future.

This chapter provides conclusions to what has been thoroughly discussed and also provides suggestions that will complement both the Statistical-based and the Correlation-based approaches for analog television signal detection on any particular spectrum frequency.

6.1 Conclusions

The Cognitive Radio concept has found a new nesting opportunity for future development on the television activity detection area. The broadcasting policies adopted by the US have brought up new alternatives and development fields on the wireless telecommunications market. It is a fact that the fast evolution demanded by wireless technology will continue to generate bigger challenges that will become interesting research problems.

A novel technique was developed on the present document and is an alternate way to face the television activity detection problem. While making use of valid mathematical and statistical principles and theories, the method proves to be a high performance SNR-optimal tool for field applications.
The designed Matched Filter based on a Barker-type pre-processes input for pattern recognition represents a low cost and efficient solution for the detection problem. The spikes coming out of the filter every time the sync pattern is found on the input signal work as an excellent indicator that may help the secondary device to assess the presence of valid TV broadcasting stations/devices on severely noisy environments where the SNR can be as low as -20dB.

By taking advantage of the signal regularities of the composite video signal, the proposed method provides an excellent correlation profile with sharp mainlobe spikes and compressed sidelobe amplitudes, while leaving the noise floor at a convenient level as to set up a detection threshold with enough margins for implementation purposes. Though the needed hardware for making the proposed idea become a tangible object is not necessarily discussed, the technique shows a straightforward path that would facilitate the instrumentation, construction and validation of any prototype device. A remarkable advantage of the proposed technique is that it does not really matter what the wireless communication technology will the next generation of devices converge to, the idea will remain valid as long as the analog standards for television broadcasting prevail.

As for spectrum usage, the method becomes an efficient and reliable tool for secondary devices to assess or discard the presence of television signaling in a particular geographical spot at relatively low processing and implementation costs.

While processing the inputs by the designed matched filter, the system might present a trade-off between response time and implementation costs. The system will have to perform a time sweep to look for a valid television pattern that the filter has been matched to. The speed of the sweep could be an important factor to determine the costs of the circuitry needed for implementation purposes. However, the method’s efficiency will be kept intact as long as the procedure is followed by the book.
6.2 Further Work

The improvement areas for the presented technique could possibly be numerous. However, a few complementing ideas are proposed as future research areas based on the main topics analyzed along the present document. The applicability of the following opportunity areas is still related to the television activity detection on a specific spot where a spectrum gap is believed to be inefficiently utilized and the spectrum reutilization is required.

6.2.1 Analysis of Interference Scenarios

Based on the existing analytical and empirical urban and suburban propagation models as well as on the proposed detection method, some interference scenarios are to be analyzed in order to particularize its applicability to real-type conditions. The analysis should provide valuable information to estimate important link budget parameters. The most important parameters and information attainable by analyzing the following particular interference scenarios would be:

- **Scenario 1**: Given a TV Transmitter (Tx) and a TV Receiver (Rx) separated by a distance $d$, it is desirable to find the largest value of $d$ (coverage contour) that allows a Mean Reception Level (threshold) of, at least, $\xi$ dBm (*i.e.* -116dBm as proposed by FCC).

![Interference Scenario 1](image)
• **Scenario 2:** It is desirable to find the maximum number (N) of interferers at a given radius (R) from a receiver, before reaching a given threshold level (*i.e.* $\xi = -114\text{dBm}$).

![Fig. 6.2 Interference Scenario 2](image)

• **Scenario 3:** It is also desirable to simulate several user densities around a receiver device, following a defined probability distribution (*i.e.* Poisson). The parameter to be calculated is the maximum allowable number of users per area unit that would ensure the produced interference is under the required tolerance limits as established by the regulating organism (*i.e.* the FCC in the US case).

![Fig. 6.3 Interference Scenario 3](image)
• **Scenario 4:** Generalization of \( N \) embedded microcells \((T_1\ldots T_N)\) into \( M \) surrounding base stations, transmitting to one mobile subscriber unit located within a reachable coverage distance.

6.2.2 Exploring the Use of Alternate Barker-type Codes

Another improvement area deals with the search for longer Barker-type Codes that may have the desired autocorrelation profile: large mainlobe compared to relatively compressed sidelobe amplitudes. Several examples of alternative *ternary* Barker Codes are proposed by Moharir in [26].

Though the proposed ternary codes have a maximum length of 10 components, the idea might be useful to expand the quest to the 18 alternating pulses on the V-Sync Sequence for the American Standard or the 15 pulses on the PAL and SECAM standards.

6.2.3 The Coverage Area Concept

An important result that might be applicable to the White Spaces estimation and measuring theory is the one developed by Jakes in [27]. Based on the outage probability calculation of a lognormal fading process, Jakes proposes the concept...
of Coverage Area and defines it as "the percentage of locations within a circle of radius \( R \) in which the received signal strength from a radiating base-antenna station exceeds a particular threshold value \( \xi \)."

The coverage area, or fractional useful service area that meets the above definition is computed by integrating the probability \( P_{\xi}(R) \) that the received signal exceeds certain threshold \( \xi \) for an incremental area \( dA \). This can be expressed as:

\[
F_u = \frac{1}{\pi R^2} \int P_{\xi}(R) dA
\]  

(6.1)

Some of the typical product results of the developments performed by Jakes have shown applicability on cell size calculations for traditional wireless networking systems. An expansion of this procedure should be studied as an alternative approach for Cognitive Radio and television activity detection areas.
Appendix

A.1 Sync Signaling & Timing in Analog TV Standards

The following timing information has been extracted from Keith’s book [5] on Chapter 8 entitled “NTSC, PAL, and SECAM Overview”. The first presented analog standard is the simplest version of a four-field SECAM sequence. The second section provides information of an eight-field PAL synchronization sequence and, finally, the third section shows typical NTSC timing information.

A.1.1 Timing in SECAM Standard

![SECAM Sync Timing Diagram](image-url)
A.1.2 Timing in PAL Standard

Fig. A.2 PAL Sync Timing
Fig. A.3 PAL Sync Timing (cont'd).
A.1.3 Timing in NTSC Standard

Fig. A.4 NTSC Sync Timing
A.2 Barker Codes Autocorrelation Functions

Fig. A.5 Barker Codes Autocorrelation Functions
A.3 Barker Pre-processed Inputs Correlation Profile

Fig. A.6 Correlation Profile for Input 4.5a

Fig. A.7 Correlation Profile for Input 4.5b
Appendix

Fig. A.8 Correlation Profile for Input 4.5c

Fig. A.9 Correlation Profile for Input 4.5d
Fig. A.10 Correlation Profile for Input 4.5e

Fig. A.11 Correlation Profile for Input 4.5f
Bibliography


