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Cyclostationary Based Spectrum Sensing in Cognitive Radio: Windowing Approach

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Abstract: ***A key challenge in operating cognitive radios (CRs) in a self-organizing (ad hoc) network is how to adaptively and efficiently allocate transmission powers and spectrum among CRs according to the surrounding environment. The growing demand of wireless applications has put a lot of constraints on the usage of available radio spectrum which is limited and precious resource. However, a fixed spectrum assignment has lead to under utilisation of spectrum as a great portion of licensed spectrum is not effectively utilised. Cognitive radio is a promising technology which provides a novel way to improve utilisation efficiency of available electromagnetic spectrum. Spectrum sensing helps to detect the spectrum holes (underutilised bands of the spectrum) providing high spectral resolution capability. In this paper cyclostationary feature based spectrum sensing technique is discussed along with the implementation of different window techniques. Cyclostationary feature can be used for spectrum sensing in a very low SNR environment.***

Keywords: ***Cognitive radio networks, Spectrum sensing, Cyclostationary feature based spectrum sensing, Window technique.***

I. INTRODUCTION

Current wireless networks are characterized by a static spectrum assignment policy where government agencies assign wireless spectrum to license holders on a long-term basis for large geographical regions. Recently, because of the increase in spectrum demand, this policy has been faced with spectrum scarcity at particular spectrum bands. On the contrary, a large portion of the assigned spectrum is still used sporadically, leading to underutilization of a significant amount of the spectrum [2]. The limited available spectrum and inefficient spectrum utilization make it necessary to develop a new communication paradigm to exploit the existing wireless spectrum opportunistically. To address these critical problems, the Federal Communications Commission (FCC) recently approved the use of unlicensed devices in licensed bands [2]. Consequently, dynamic spectrum access techniques are proposed to solve these current spectrum inefficiency problems [3].

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The key enabling technology for dynamic spectrum access techniques is cognitive radio (CR) networking, which allows intelligent spectrum-aware devices to opportunistically use the licensed spectrum bands for transmission [4].

The term cognitive radio can formally be defined as follows [5]: A cognitive radio is a radio that can change its transmitter parameters based on interaction with the environment in which it operates.

The following are the main features of spectrum management functions [8]:

Spectrum sensing: A CR user should monitor the available spectrum bands, capture their information, and then detect spectrum holes. Spectrum sensing is a basic functionality in CR networks, and hence closely related to other spectrum management functions as well as layering protocols to provide information on spectrum availability.

Spectrum decision: Once the available spectra are identified, it is essential that CR users select the best available band according to their QoS requirements.

Spectrum sharing: Spectrum sharing includes channel and power allocations to avoid interference caused to the primary network and a CR medium access control (MAC) protocol along with spectrum sensing.

Spectrum mobility: If the specific portion of the spectrum in use is required by a PU, the communication must be switched to another vacant portion of the spectrum.

Sensing external radio environment quickly and accurately plays a key role in cognitive radio. Energy detection [1], matched filter detection [1], and cyclostationary feature detection [1] are three commonly used spectrum sensing methods. Energy detection is easy to implement, but its performance degrades greatly under low signal-to- noise ratio (SNR) or with noise uncertainty. Match filter detection can detect signals with low SNR, but it needs the licensed user's prior knowledge and perfect synchronization, which is hard to realize in reality.

Cyclostationary feature detection is a method for detecting primary user transmissions by exploiting the cyclostationarity features of the received signals. Cyclostationary features are caused by the periodicity in the signal or in its statistics like mean and autocorrelation or they can be intentionally induced to assist spectrum sensing.

II. PRINCIPLE OF CYCLOSTATIONARITY

A signal is said to be stationary if its frequency or spectral contents are not changing with respect to time.

This is because when we generate a sine wave using either a function generator or software, we selected the frequency value and kept it constant forever. Thus the frequency content of the sine wave will not change with time and hence is an example for stationary signal. Suppose if you change the frequency, then it altogether becomes a new sine wave. Stationarity is linked to the behaviour of the frequency contents of the signal with respect to time and nothing else.

A cyclostationary process is a signal having statistical properties that vary cyclically with time. A cyclostationary process can be viewed as multiple interleaved stationary processes. These processes are not periodic function of time but their statistical features indicate periodicities. The following conditions are essential to be filled by a process for it to be wide sense cyclo-stationary [9]:

$$E\{x(t+T_0)\} = E\{x(t)\} \tag{2.1}$$

$$R_x(t+T_0,\tau) = R_x(t,\tau) \tag{2.2}$$

$$where R_x = E\{x(t+\tau)x(t)\} \tag{2.3}$$

Thus both the mean and auto-correlation function for such a process needs to be periodic with some period say T0. The cyclic auto-correlation function (CAF) is represented in terms of Fourier co-efficient as:

$$R_x^{n/T_0}(\tau) = \frac{1}{T_0}\int_{-T_0/2}^{T_0/2} R_x(t,\tau)e^{-j2\pi(n/T_0)t}dt \tag{2.4}$$

Where 'n/T0' represent the cyclic frequencies and can be written as 'α' . The Cyclic Spectral Density (CSD) representing the time averaged correlation between two spectral components of a process which are separated in frequencies by 'α' is given as :

$$S(f,\alpha) = \int_{\tau=-\infty}^{\infty} R_x^{\alpha}(\tau)e^{-j2\pi f\tau}d\tau \tag{2.5}$$

The cyclic spectrum density (CSD) represents the density of the correlation between two spectral components.

III. WINDOW FUNCTION

In signal processing, a window function is a mathematical function that is zero-valued outside of some chosen interval. Applications of window functions include spectral analysis, filter design, and beam forming. In typical applications, the window functions used are non-negative smooth "bell-shaped" curves, though rectangle, triangle, and other functions can be used. Different types of window functions are discussed below:

The Rectangular window is the simplest window, equivalent to replacing all but *N* values of a data sequence by zeros, making it appear as though the waveform suddenly turns on and off:

$$\omega(n) = 1 \tag{3.1}$$

The transfer function of Triangular window is given by:

$$\omega(n) = 1 - \left| \frac{n - \frac{N-1}{2}}{\frac{L}{2}} \right| \tag{3.2}$$

Where, 'L' can be 'N', 'N+1' or 'N-1'.

The transfer function of Hanning window is given by:

$$\omega(n) = 0.5\left(1-\cos\left(\frac{2\pi n}{N-1}\right)\right) \tag{3.3}$$

For zero-phase the transfer function is given by:

$$\omega_0(n) = 0.5\left(1+\cos\left(\frac{2\pi n}{N-1}\right)\right) \tag{3.4}$$

The hamming window is optimized to minimize the maximum (nearest) side lobe, giving it a height of about one-fifth that of the hanning window. Its transfer function is given by:

$$\omega(n) = \alpha - \beta\cos\left(\frac{2\pi n}{N-1}\right) \tag{3.5}$$

For zero-phase the transfer function is given by:

$$\omega_0(n) = \alpha + \beta\cos\left(\frac{2\pi n}{N-1}\right) \tag{3.6}$$

Where, $\alpha = 0.54, \beta = 1-\alpha = 0.46$

The transfer function of Blackman window is given by:

$$\omega(n) = a_0 - a_1\cos\left(\frac{2\pi n}{N-1}\right) + a_2\cos\left(\frac{4\pi n}{N-1}\right) \tag{3.7}$$

Where,

$$a_0 = \frac{1-\alpha}{2}, a_1 = \frac{1}{2}, a_2 = \frac{\alpha}{2}$$

The transfer function of the Kaiser window is given by:

$$\omega(n) = \frac{I_0\left(\pi\alpha\sqrt{1-\left(\frac{2\pi}{N-1}-1\right)^2}\right)}{I_0(\pi\alpha)} \tag{3.8}$$

For zero-phase the transfer function is given by:

$$\omega(n) = \frac{I_0\left(\pi\alpha\sqrt{1-\left(\frac{2\pi}{N-1}\right)^2}\right)}{I_0(\pi\alpha)} \tag{3.9}$$

Where I_0 is the zero-th order modified Bessel function of the first kind. Variable parameter α determines the trade off between main lobe width and side lobe levels of the spectral leakage pattern.

IV. CYCLOSTATIONARY FEATURE DETECTION

Cyclostationary feature detection is robust to noise uncertainties and performs better than energy detection in low SNR regions. It exploits the periodicity in the received primary signal to identify the presence of primary users (PU). Due to the periodicity, these cyclostationary signals exhibit the features of periodic statistics and spectral correlation. The block diagram and algorithm for sensing the spectrum are given below:

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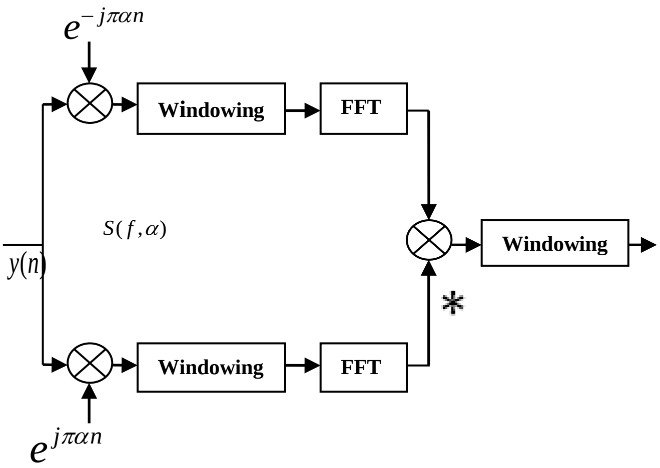

Figure 1: Block diagram of Cyclostationary Feature Detection method

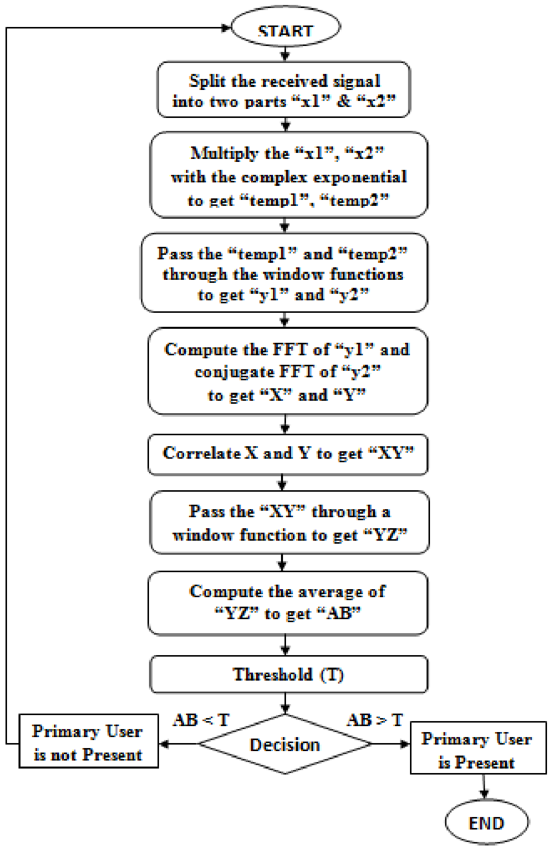

Figure 2: Flow diagram of Cyclostationary Feature Detection

In order to implement the cyclostationary detector [9] the following steps are followed:

Let

n= message length
nv= overlap number
nw= window size
hw=window size
nfft= fft size

The signal of interest say 'x(t)' is shifted in time domain by '-α/2' and 'α/2' as:

$$temp_1(n) = x_1(n).e^{-j2\pi(\alpha/2)n} \quad (4.1)$$

$$temp_2(n) = x_2(n).e^{j2\pi(\alpha/2)n} \quad (4.2)$$

Now both the shifted signals are passed through one window having the window size of 'nw':

$$y_1(n) = temp_1(n).window(nw) \quad (4.3)$$

$$y_2(n) = temp_2(n).window(nw) \quad (4.4)$$

Now Fourier transform of these windowed signals are found out:

$$X(f) = fft(y_1, nfft) \quad (4.5)$$

$$Y(f) = fft(y_2, nfft) \quad (4.6)$$

Spectral correlation function for each frame is found out:

$$XY(f) = X(f).conj(Y(f)) \quad (4.7)$$

Again the signal 'XY' is passed through another window having the window size of 'hw':

$$YZ(f) = XY(f).window(hw) \quad (4.8)$$

Again taking the average of the 'YZ' with respect to the number sample 'N':

$$AB(f) = \frac{1}{N}\sum_{i=1}^{N} YZ_i(f) \quad (4.9)$$

Then the average 'AB' will be compared with the threshold 'T'. If the signal value is above the threshold value then the primary user (PU) is detected. Otherwise the channel is free and it can be assigned to secondary user (SU). The threshold can be calculated by the formula [10]:

$$T = \sigma\sqrt{2\log(N)} \quad (4.10)$$

Where 'σ' is the "noise level" and is given by:

$$\sigma = MAD/0.6745 \quad (4.11)$$

And "MAD" is the Median Absolute Deviation.

V. RESULTS AND ANALYSIS

An extensive set of simulations have been conducted using the system model as described in the previous section. The emphasis is to analyze the comparative study of different window techniques during spectrum sensing. The performance metrics used for comparison include the "no. of free channels that can be assigned to secondary users" and "no. of channels used by the primary users". In the below figures the top part indicates the presence of primary users and in bottom part indicates the absence of primary users i.e these channels can be used by the secondary users. The outputs of different windows are given below:

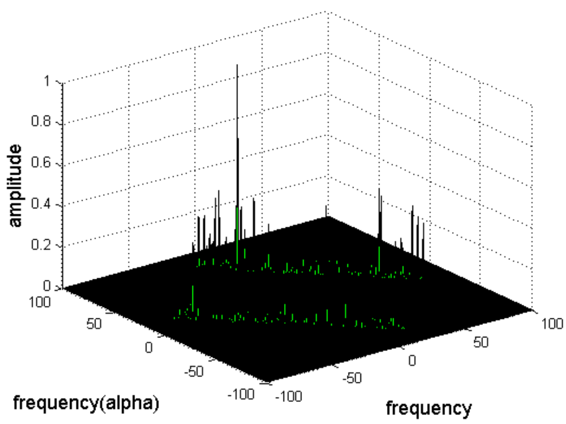

Figure 3.1: Indicates presence of primary user by passing the signal through "Rectangular window".

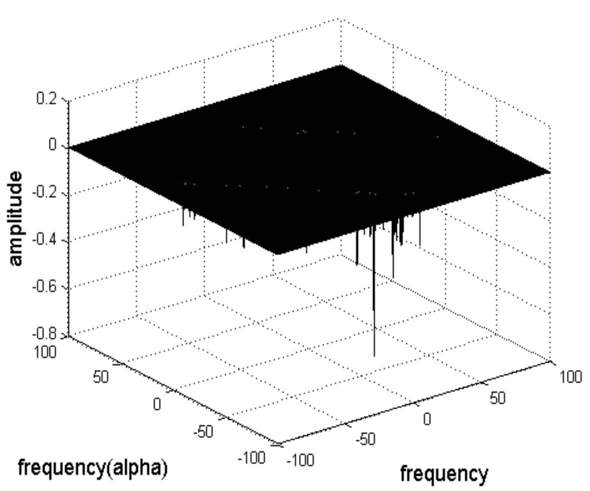

Figure 3.2: Indicates absence of primary user by passing the signal through "Rectangular window"

From the analysis of rectangular window it is found that the transition width of main lobe is very less but its peak side lobe is very high. It contains a large number of side lobes which may increase the spectral leakage.

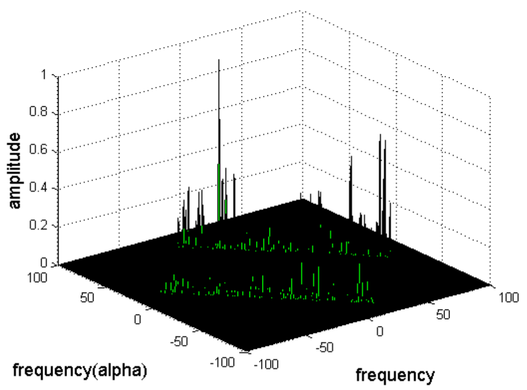

Figure 4.1: Indicates presence of primary user by passing the signal through "Triangular window"

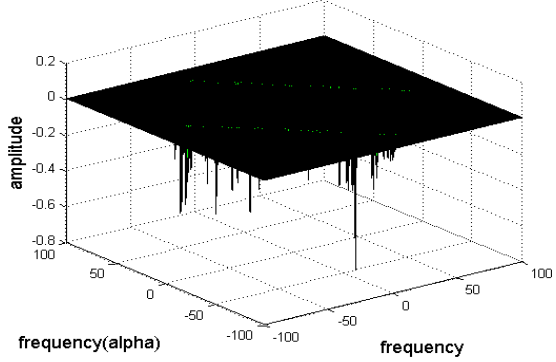

Figure 4.2: Indicates absence of primary user by passing the signal through "Triangular window"

From the analysis of triangular window it is found that the transition width of main lobe is more than rectangular window but less than the hanning window and its peak side lobe and spectral leakage are less than the rectangular window but more than the hanning window.

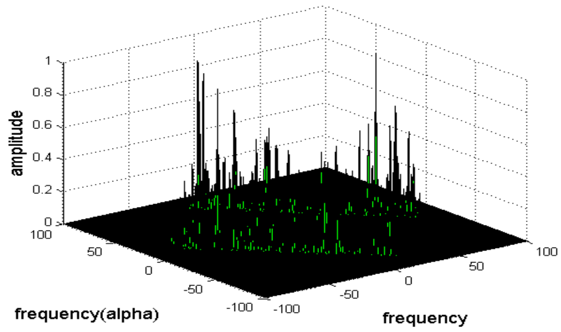

Figure 5.1: Indicates presence of primary user by passing the signal through "Hanning window"

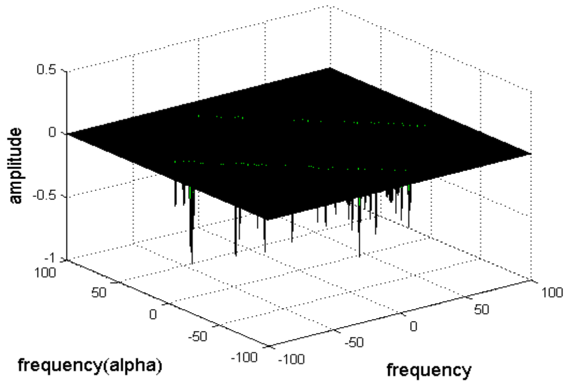

Figure 5.1: Indicates absence of primary user by passing the signal through "Hanning window"

From the analysis of hanning window it is found that the transition width of main lobe is more than rectangular window and triangular window but almost equal than the hamming window and its peak side lobe and spectral leakage are less than the rectangular window and triangular window but more than the hamming window. Here in the above diagram we have got more number of high amplitude signals than rectangular window and triangular window.

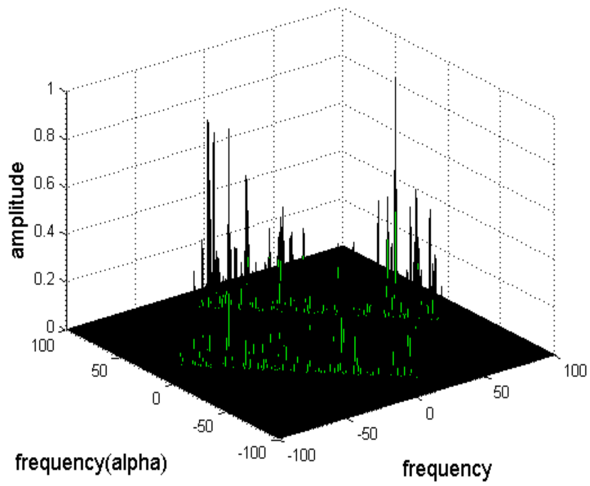

Figure 6.1: Indicates presence of primary user by passing the signal through "Hamming window"

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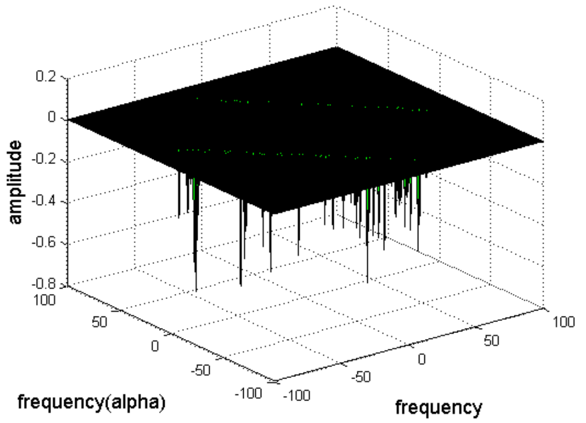

Figure 6.2: Indicates absence of primary user by passing the signal through "Hamming window"

From the analysis of hamming window it is found that the transition width of main lobe is more than rectangular window and triangular window but almost equal than the hanning window and its peak side lobe and spectral leakage are less than the rectangular window and triangular window and hanning window.

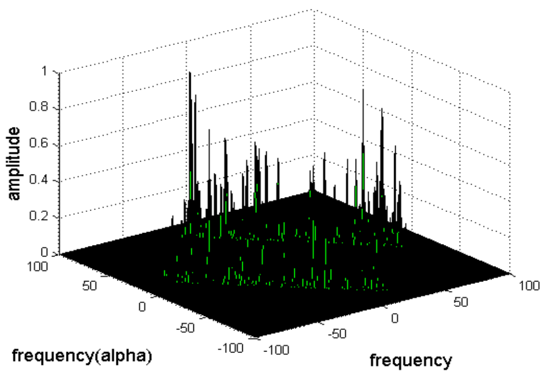

Figure 7.1: Indicates presence of primary user by passing the signal through "Blackman window"

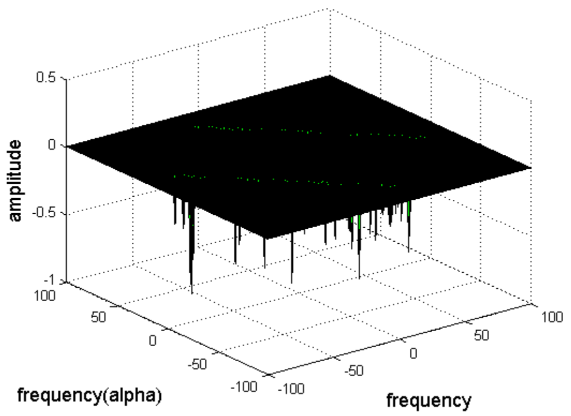

Figure 7.2: Indicates absence of primary user by passing the signal through "Blackman window"

From the analysis of blackman window it is found that the transition width of main lobe is more than rectangular, triangular, hanning and hamming windows and its peak side lobe and spectral leakage are less than the rectangular, triangular, hanning and hamming windows. So in this case we are getting more number of high amplitude signals.

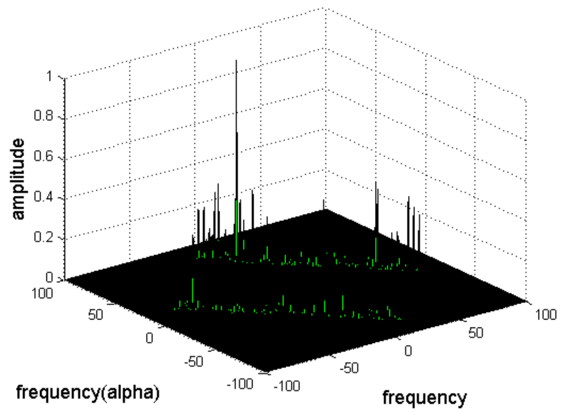

Figure 8.1: Indicates presence of primary user by passing the signal through "Kaiser window"

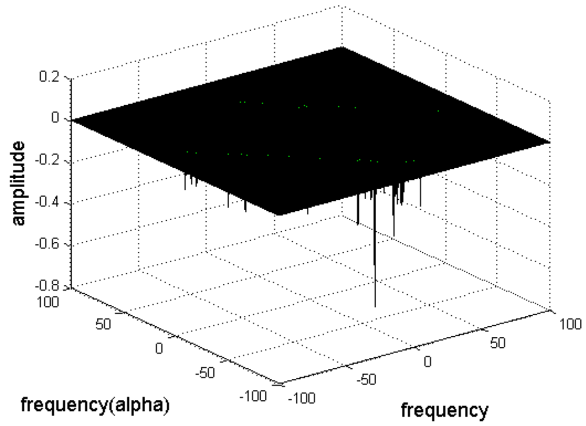

Figure 8.2: Indicates absence of primary user by passing the signal through "Kaiser window"

From the analysis of kaiser window it is found that the transition width of main lobe is dependent upon the Kaiser window parameter 'α'. If 'α' is less, then its transition width of main lobe and peak side lobe can be comparable to rectangular window and if 'α' is more, then it can be comparable with other windows.

Table 1: No. of frequency components indicates the presence of PU and absence of PU

Types of Window	1st Iteration		2nd Iteration		3rd Iteration		4th Iteration	
	P	Q	P	Q	P	Q	P	Q
Rectangular	14715	50565	14099	51181	13252	52028	13252	52028
Triangular	62615	2665	4470	60810	4590	60690	4590	60690
Hanning	63717	1563	1622	63658	62782	2498	62782	2498
Hamming	59369	5911	13442	51838	50088	15192	50088	15192

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Black man	640 27	125 3	133 6	639 44	144 0	638 40	144 0	638 40
Kaiser	148 00	504 80	142 09	510 71	133 32	519 48	133 32	519 48

In the above table 'P' indicates the no. of frequency components in which the primary users (PU) are detected and 'Q' indicates the no. of frequency components in which the primary users are not detected and these frequency components or channels can be assigned to the secondary users.

VI. CONCLUSION

In this paper we studied how to sense a particular spectrum by using cyclostationary detection method. Here also we passed the received signal in the output side into different windows and found out the autocorrelation of different signals from each window and verified the channels occupied by the primary users as well as the channels not occupied by the primary users. The channels that are not occupied by the primary users can be assigned to the secondary users. According to the above table it is concluded that very less variations are occurred during the evaluation of no. of frequency components to detect presence of PU and absence of PU by taking multiple iterations. So it is also concluded that the best performance can be achieved by passing the signal through the "Rectangular window" and "Kaiser window".

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