Effect of shape parameter ‘α’ in Kaiser-Hamming and Hann-Poisson Window Functions on SNR Improvement of MST Radar Signals

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Abstract

In this paper the effect of window shape parameter ‘α’ in Kaiser-Hamming and Hann-Poisson window functions on the signal to noise ratio (SNR) values of the Indian Mesosphere-Stratosphere-Troposphere (MST) radar is computed. The six parts of multibeam observations of the lower atmosphere made by the MST radar are utilized for the analysis of results. Prior to the Fourier transformation, the in-phase and quadrature components of radar echo samples are weighted with proposed windows based on the Kaiser-Hamming and Hann-Poisson Window functions. The effects of data weighting with the change of the window shape parameter ‘α’ of the Kaiser-Hamming and Hann-Poisson Window functions are given in it. It is noted that the increase of variable window shape parameter ‘α’ increases the signal to noise ratio values and a better improvement is reported. For Kaiser-Hamming and Hann-Poisson Window functions are proposed to analyze the MST radar return signals to obtain optimum values of the window shape parameter. The results shows the improvement of signal to noise ratio of noisy data due to the effect of side lobe reduction and demands for the design of the optimal window functions.

Index Terms: Kaiser-Hamming and Hann-Poisson window functions, SNR, DFT and Spectral Analysis.

1. Introduction

The discrete Fourier transform (DFT) in Harmonic analysis plays a major role in the radar signal processing. The data weighting window function with the DFT [7,10,18] is used to resolves the frequency components of the signal buried under the noise. The inappropriate window gives the corrosion in the principal spectral parameters, hence it is ordered to consider criteria by the choice of data weighting window is used and made [24]. It was observed that the effect of ‘α’ in proposed windows based on the Kaiser-Hamming [12] and Hann-Poisson [13] functions on SNR of MST radar return signals and proposed an optimum value of window shape parameter with data.

2. Data Weighting Windows

Windows are time-domain weighting functions are used in various signal processing applications, like beam forming, energy spectral estimation, power spectral estimation and digital filter design. Window functions are used to classify the cosmic data [2,21] and to increase the reliability of weather prediction models [14]. The application of FFT to a finite duration data gives the spectral leakage effect and picket fence effect. The data weighting window functions [25] can reduce these effects. The use of the data window functions affects the frequency resolution, variance and bias of the spectral estimations [10,18]. It is estimated that the number of observations are increased if the bias and variance tends to zero. Thus the problem with the spectral estimation of a finite duration data by the Fast Fourier Transformation method is the effect of providing efficient data windows or data smoothing schemes.

The data window functions are utilized to weight the time series of the quadrature phase and in-phase components of the radar return signals before to apply the DFT. The observed Doppler spectra represent the convolutions of the Fourier transforms of original signals projected onto the discrete frequencies [7].

3. Spectral Leakage

For signal frequencies, observed through the rectangular window, which do not correspond exactly to one of the sampling frequencies, the pattern is shifted such that non-zero values are projected onto all sampling frequencies. This phenomenon of spreading signal power from the nominal frequency across the entire width of the observed spectrum is called as spectral leakage [1,6,7]. The data windowing effect on the SNR improvement of MST radar returns signals are reported in literature [4,8,15,16,17,20]. By choosing the suitable values of shape parameters of adjustable windows, it is
easy to provide SNR improvement with the optimum shape parameters [4,15,16,17]. Windows are classified into fixed or adjustable [23]. Fixed windows consist of only one independent parameter that is length of window; it controls the width of the main-lobe. The variable window functions having two or more independent parameters that can control other window characteristics [7,9]. The Kaiser and Saramaki windows [8,19] consist of two parameters and it provides close approximations to prolate discrete function to analyze the maximum energy concentration in main lobe. The Dolph-Chebyshev window [4], [9] consists of two parameters and provides the minimum main-lobe width for maximum side-lobe level. For various applications the characteristics of main lobe width and ripple ratio can be controlled by adjusting two independent parameters like the window length and shape parameter. Kaiser window has a better side lobe roll-off characteristic other than the adjustable windows like Dolph-Chebyshev [4] and Saramaki [19] are special cases of ultra spherical window [26]. The quasi-monotonic (atmospheric) signal is superimposed on the background of white noise which is composed by the atmospheric radar. The spectral leakage from the signal exceeds the noise level computed with the help of Hildebrand and Sekhon [5] method and its response to underestimate signal-to-noise ratio.

4. Window Functions

Kaiser-Hamming Window

It is obtained by combining a Kaiser window[3] and Hamming window and is defined in discrete time domain is

\[ w_{KH}(n, \alpha) = \begin{cases} 0.54 + 0.46 \cos \left( \frac{2\pi n}{N} \right) + \frac{l_0 \left( \frac{\sqrt{1 - \left( \frac{2n}{N} \right)^2}}{\sqrt{1 - \left( \frac{n}{N} \right)^2}} \right)}{l_0(\alpha)} & , |n| \leq \frac{N-1}{2} \\ 0, & otherwise \end{cases} \]  

(1)

Hann-Poisson Window

It is obtained by combining a Hann window and Poisson window functions[12] and is defined in discrete time domain is

\[ w_{HP}(n, \alpha) = \begin{cases} \frac{1}{2} \left( 1 + \cos \left( \frac{2\pi n}{N} \right) \right) \exp \left( -\alpha \frac{2|n|}{N} \right), & |n| \leq \frac{N-1}{2} \\ 0, & otherwise \end{cases} \]  

(2)

Kaiser Window

The Kaiser Window function [3] is defined by

\[ w_{K}(n, \alpha) = \begin{cases} l_0 \left( \alpha \sqrt{1 - \left( \frac{2n}{N} \right)^2} \right) \frac{\sqrt{1 - \left( \frac{n}{N} \right)^2}}{l_0(\alpha)} & , |n| \leq \frac{N-1}{2} \\ 0, & otherwise \end{cases} \]  

(3)

Where ‘α’ is the adjustable window shape parameter and the parameter “α” is a controlling parameter on the SNR of the MST radar signals.

5. Kaiser-Hamming and Hann-Poisson Window functions applied to MST radar signals

The signal which is received by MST radar due to back scattering of atmospheric layers, the atmospheric radar signals is turbulent. The radar return signals from the atmospheric layers having very small amount of power and are emitted from it. These signals are associated with Gaussian noise. This noise dominates the signal strength as the distance between the target and radar increases, it leads to decrease in signal to noise ratio so the detection of the signal is difficult. The information on Doppler profile is provided from the power spectrum using FFT. The frequency characteristics of radar return signals are analyzed with power spectrum; this specifies the spectral characteristics of frequency domain signals.

The specifications of the MST radar data are given in Table 1. The signal to noise ratio analysis on MST radar data corresponds to the lower stratosphere obtained from the NARL, Gadanki, India. The operation of radar was perform in East, West, North, South, Zenith-X and Zenith-Y direction in vertical direction of an angle of 10°. The data collected from the six directions of MST radar are used to carry on the signal to noise ratio analysis. The algorithm which is shown below uses MATLAB to observe the effect of window shape parameter ‘α’ and a controlling parameter ‘ε’ on the SNR of the MST radar signals.

6. Algorithm and Data Specifications

- Obtain the Kaiser-Hamming and Hann-Poisson windows with the specified values of ‘α’
- Tapering the radar data with window function weights specified in first step
- Compute the Fourier analysis of the above
tapered data [11,22,23].
- Calculate the signal to noise ratio using the procedure [5,11,22,23].
- Calculate the Mean Value below Zero signal to noise ratios (MVBZ) [4,16,17]
- Calculate the Mean Value above Zero signal to noise ratios (MVAZ) [4,16,17]
- Update the value of ‘α’ repeat above steps except first step

The MST radar data is used for the computation of mean signal to noise ratio is

No. of Range Bins : 150
No. of FFT points : 512
No. of Coherent Integrations : 64
No. of Incoherent Integrations : 1
Inter Pulse Period : 1000 μsec
Pulse Width : 16 μsec
Beam : 10°

Table 1: Specifications of MST radar

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period of Observation</td>
<td>July 2011</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>16 μs</td>
</tr>
<tr>
<td>Range resolution</td>
<td>150 m</td>
</tr>
<tr>
<td>Inter Pulse Period</td>
<td>1000 μs</td>
</tr>
<tr>
<td>Number of Beams</td>
<td>6(E_{10y},W_{10y},N_{10x},S_{10x},Z_{x},Z_{y})</td>
</tr>
<tr>
<td>Number of FFT points</td>
<td>512</td>
</tr>
<tr>
<td>No. of Incoherent Integrations</td>
<td>1</td>
</tr>
<tr>
<td>Maximum Doppler Frequency</td>
<td>3.9 Hz</td>
</tr>
<tr>
<td>Maximum Doppler Velocity</td>
<td>10.94 m/s</td>
</tr>
<tr>
<td>Frequency resolution</td>
<td>0.061 Hz</td>
</tr>
</tbody>
</table>

E_{10y}=East West polarization with off-zenith angle of 10°
W_{10y}=East West polarization with off-zenith angle of 10°
N_{10x}=North South polarization with off-zenith angle of 10°
S_{10x}=North South polarization with off-zenith angle of 10°

7. Results

Average SNR of radar data for Kaiser-Hamming, Hann-Poisson and Kaiser windows as shown in Fig. 1 ,2 and 3 res.
Fig. 1(e): Average SNR ZENITH-X Beam

Fig. 1(f): Average SNR ZENITH-Y Beam

Fig. 2(a): Average SNR EAST Beam

Fig. 2(b): Average SNR WEST Beam

Fig. 2(c): Average SNR NORTH Beam

Fig. 2(d): Average SNR SOUTH Beam

Fig. 2(e): Average SNR ZENITH-X Beam

Fig. 2(f): Average SNR ZENITH-Y Beam
The comparison of Kaiser-Hamming and Hann-Poisson Window functions in terms of MVAZ SNR and MVBZ SNR of six directions of MST radar as shown in Table 2.

Table 2: Comparison of Windows for $\alpha=6$.

<table>
<thead>
<tr>
<th>Window/Performance</th>
<th>Kaiser-Hamming window</th>
<th>Hann-Poisson window</th>
<th>Kaiser window</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVAZ East Beam</td>
<td>9.0492</td>
<td>9.4716</td>
<td>9.023</td>
</tr>
<tr>
<td>MVBZ East Beam</td>
<td>-7.7183</td>
<td>-6.3467</td>
<td>-7.458</td>
</tr>
<tr>
<td>MVAZ West Beam</td>
<td>9.456</td>
<td>10.1221</td>
<td>9.817</td>
</tr>
<tr>
<td>MVBZ West Beam</td>
<td>-7.3926</td>
<td>-6.1929</td>
<td>-7.401</td>
</tr>
<tr>
<td>MVAZ North Beam</td>
<td>12.3676</td>
<td>11.5285</td>
<td>11.99</td>
</tr>
<tr>
<td>MVBZ North Beam</td>
<td>-8.6476</td>
<td>-7.4632</td>
<td>-9.049</td>
</tr>
<tr>
<td>MVAZ South Beam</td>
<td>11.3309</td>
<td>11.6286</td>
<td>11.45</td>
</tr>
<tr>
<td>MVBZ South Beam</td>
<td>-7.9159</td>
<td>-5.9061</td>
<td>-7.717</td>
</tr>
<tr>
<td>MVAZ Zenith-X Beam</td>
<td>12.6054</td>
<td>11.0969</td>
<td>12.51</td>
</tr>
<tr>
<td>MVBZ Zenith-X Beam</td>
<td>-7.7399</td>
<td>-6.4615</td>
<td>-7.935</td>
</tr>
<tr>
<td>MVAZ Zenith-Y Beam</td>
<td>14.4563</td>
<td>14.0508</td>
<td>14.34</td>
</tr>
<tr>
<td>MVBZ Zenith-Y Beam</td>
<td>-7.8919</td>
<td>-7.0831</td>
<td>-7.718</td>
</tr>
</tbody>
</table>
8. Conclusion

The SNR values for the six sets of MST radar data and performance analysis of Kaiser-Hamming and Hann-Poisson Window functions is computed. The MVBZ SNR increases with adjustable window shape parameter. The increase in MVBZ continues up to a certain value of the adjustable window shape parameters. Further increase in adjustable parameters has no appreciable change in MVBZ SNR. It is clearly shows that even the change in side lobe reduction contributes to the SNR improvement at the cost of main lobe width and it shows the improvement in SNR. By increasing the adjustable window shape parameters the side lobe level is decrease and width of main lobe is the increases which compensates the increase in the MVBZ SNR. Therefore the MVBZ SNR value is almost constant of all the six sets of radar data. For all the six-sets of radar data there is no appreciable change in the MVAZ SNR with adjustable window shape parameters. This result provides the back-scattered signal from the middle and upper most bins are very weak, improvement in SNR is more important in spectral estimation. For obtaining a good signal to noise ratio improvement, the selection of the adjustable window shape parameters plays an important role.

References