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Research Paper

THE EFFECT OF PLANCK-BESSEL / 3COSH / KAISR WINDOW FUNCTION PARAMETERS CG-ICG-ENBW-SL ON SNR IMPROVEMENT OF MST RADAR SIGNALS

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In this paper, the effect of Planck-Bessel, 3Cosh and Kaiser Window parameters CG, ICG, ENBW and SL on the SNR values of the 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 Planck-Bessel, 3Cosh and Kaiser Window functions. It is noted that the increase of adjustable shape parameter '~', controlling parameter '£' and cost function '*p*' of Planck-Bessel, 3Cosh and Kaiser window increases ENBW and SL but decreases the CG and ICG. It helps to improve the SNR of MST radar return samples. Thus it is reported that the '~= 6', '£= 0.1' and '*p* = 0.7' can be suggested for good results of SNR improvement in MST radar return signals. The optimum window parameters in turn yields optimum Planck-Bessel window function parameters are 'CG = 0.4920, ICG = 0.3653, ENBW = 1.5091, SL = 0.8502', 3Cosh window function parameters are 'CG = 0.655, ICG = 0.5111, ENBW = 1.1914, SL = 0.7712' and Kaiser Window function parameters are 'CG = 0.4991, ICG = 0.3660, ENBW = 1.4695, SL = 0.8410'. This relates to optimum main lobe width and side lobe attenuation to increase the signal to noise ratio of MST radar noisy data.

Keywords: CG, ICG, ENBW, SL, SNR, DFT, Spectral analysis

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 (James Fredric Harris, 1978; Marple, 1987; and Kay, 1988) is used to resolves the frequency components of the signal buried under the noise. The inappropriate window gives the corruption in the principal spectral parameters, hence it is

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ordered to consider criteria by the choice of data weighting window is used and made (Woodman Ronald, 1985). It was observed that the effects of '~', '£' and '*p*' in recently proposed adjustable windows based on the Planck-Bessel (Prabhu, 1999), 3Cosh (Nouri *et al.*, 2011) and Kaiser Window (Fredric Kaiser and Ronald Woodman, 1980) functions on SNR of MST radar return signals. This paper presents the effect of the Planck-Bessel, 3Cosh and Kaiser Window parameters CG, ICG, ENBW and SL on the SNR values of the MST radar return signals and proposed an optimum value of '~' , '£' and '*p*' with data.

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 (Torbet *et al.*, 1999; and Picard *et al.*, 2002) and to increase the reliability of weather prediction models (Lynch, 1997). The application of FFT to a finite duration data gives the spectral leakage effect and picket fence effect. The data weighting window functions (Schafer Ronald and Oppenheim, 1998) can reduce these effects. The use of the data window functions affects the frequency resolution, variance and bias of the spectral estimations (Marple, 1987; and Kay, 1988). 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 (James Fredric Harris, 1978).

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 (James Fredric Harris, 1978; Antoniou Andrwas, 1999; and Hooper, 1999). The data windowing effect on the SNR improvement of MST radar returns signals are reported in literature (Kaiser, 1974; Reddy *et al.*, 2006; Reddy Harnadh *et al.*, 2007; Reddy *et al.*, 2008; Harnadth Reddy *et al.*, 2009; and Reddy Harnadth *et al.*, 2010). By choosing the suitable values of shape parameters of adjustable windows, it is easy to provide SNR improvement with the optimum shape parameters (Reddy Harnadh *et al.*, 2007; Reddy *et al.*, 2008; Harnadth Reddy *et al.*, 2009; and Reddy Harnadth *et al.*, 2010). Windows are classified into fixed or adjustable (Anandan, 1999). 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 (Rabiner *et al.*, 1976; and James Fredric Harris, 1978). The Kaiser and Saramaki windows (Kaiser, 1974; and Saramki, 1993) 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 (Rabiner *et al.*, 1976; and Harnadth Reddy *et al.*, 2009) 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 (Harnadth Reddy *et al.*, 2009) and Saramaki (Saramki, 1993) are special cases of ultra spherical window. 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 (1974) method and its response to underestimate signal-to-noise ratio.

WINDOW FUNCTIONS

Planck-Bessel Window

The form of the Planck-Taper window (Prabhu, 1999) is inspired by the Planck distribution and is given as:

$$w_{PT}(n, \pounds) = \begin{cases} \dfrac{1}{\exp(Z_+)+1} & 0 \le n < \pounds(N-1) \\ 1 & \pounds(N-1) < n < (1-\pounds)(N-1) \\ \dfrac{1}{\exp(-Z_-)+1} & (1-\pounds)(N-1) < n \le (N-1) \\ 0 & Otherwise \end{cases} \quad ...(1)$$

where

$$Z_{\pm}(n, \pounds) = 2\pounds\left[\frac{1}{1 \pm 2n/(N-1)} + \frac{1}{1-2\pounds \pm 2n/(N-1)}\right] \quad ...(2)$$

The Planck-Bessel window is obtained by multiplying a Planck-taper window with Kaiser Window and is defined as:

$$w_{PE}(n, \sim, \pounds) = w_{PT}(n, \pounds) * w_K(n, \sim) \quad ...(3)$$

COSH WINDOW

This window is based on the cosine hyperbolic window function (Nouri *et al.*, 2011) that is optimized by applying a cost function for diminishing ripple ratio and is defined as

$$w_{PC}(n, \sim, p) = \begin{cases} \dfrac{\cosh\left[\sim\sqrt{1-\left(\dfrac{2n}{N-1}\right)}\right]^p}{\cosh(\sim, p)} & |n| \le \dfrac{N-1}{2} \\ 0 & Otherwise \end{cases} \quad ...(4)$$

where '~' is the adjustable shape parameter and '*p*' is a cost function

Kaiser Window

The Kaiser Window function (Fredric Kaiser and Ronald Woodman, 1980) is defined by

$$w_K(n, \sim) = \begin{cases} \dfrac{I_o\left(\sim\sqrt{1-\left(\dfrac{2n}{N-1}\right)^2}\right)}{I_o(\sim)} & |n| \le \dfrac{N-1}{2} \\ 0 & Otherwise \end{cases} \quad ...(5)$$

where '~' is the adjustable window shape parameter and $I_o(x)$ is characterized by the power series expansion as:

$$I_o(x) = 1 + \sum_{k=1}^{\infty}\left(\frac{1}{k!}\left(\frac{x}{2}\right)^k\right)^z \quad ...(6)$$

The parameters like length of the sequence *N*, a window shape parameter '~', a controlling parameter '£' and a cost function '*p*' are useful to get the desired amplitude response pattern of the above windows. Consider the number of FFT points in the MST radar data for each range bin is 512; the window length N is equal to 512. Therefore the '~', '£' and '*p*' can be varied to obtain the suitable window function for the desired pattern of the magnitude response. As the '~', '£' and '*p*' increases the magnitude response of side lobe level decreases at the cost of main lobe width (James Fredric Harris, 1978; Marple, 1987; and Kay, 1988). The results of SNR improvement of MST radar data are determined in form of MVBZ (Mean Value Below Zero) signal to noise ratio and MVAZ (Mean Value Above Zero) signal to noise ratio (Reddy *et al.*, 2006; Reddy Harnadh *et al.*, 2007; Reddy *et al.*, 2008; Harnadth Reddy *et al.*, 2009; and Reddy Harnadth *et al.*, 2010).

ANALYSIS OF WINDOW PERFORMANCE

The performance of window functions can be calculated from figure of merits like Incoherent Power Gain (ICG), Coherent Gain (CG), Equivalent Noise Band Width (ENBW) and Scalloping Loss (SL).

Coherent Gain

The average value of the window $w(nT)$ is called the Coherent Gain (*CG*) and is defined as:

$$CG = \frac{1}{N}\sum_{n} w(nT) \qquad ...(7)$$

The Coherent Gain value of rectangular window is unity. In other windows its value is decreases because the window smoothly going to zero at the ends. It shows the reduction in signal power.

Incoherent Power Gain

The average value of the square of window w (*nT*) is called the Incoherent Power Gain (*ICG*) and is defined as:

$$ICG = \frac{1}{N}\sum_{n} [w(nT)]^2 \qquad ...(8)$$

Its value of rectangular window is unity and other windows it is decreases.

Equivalent Noise Band Width

The ratio between ICG and square of CG is called Equivalent Noise Band Width (*ENBW*) and is defined as:

$$ENBW = \frac{ICG}{[CG]^2} = N\frac{\sum_n [w(nT)]^2}{\left[\sum_n w(nT)\right]^2} \qquad ...(9)$$

It calculates the ability of a window function to extract the signal from back ground noise. The small value of ENBW provides better signal extraction from back ground noise. The ENBW value of rectangular window is unity and for other windows it is greater than unity.

Scalloping Loss

It is the ratio of signal frequency component power gain located halfway between DFT bins to the average value of the window (Coherent Gain) for a signal frequency component located exactly on the DFT bin

$$SL = \frac{\left|\sum_n w(nT)e^{-j\pi(n/N)}\right|}{\sum_n w(nT)} \qquad ...(10)$$

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 shape parameter '~', a controlling parameter '£' and a cost function '*p*' on the SNR of the MST radar signals.

ALGORITHM-DATA-SPECIFICATIONS

- Obtain the Planck-Bessel, 3Cosh and Kaiser windows with the specified '~', '£' and '*p*'.
- Tapering the radar data with window function weights specified in first step.
- Compute the Fourier analysis of the above tapered data (Mitra, 1998; and Anandan, 1998 and 1999).
- Calculate the signal to noise ratio using the procedure (Hildebrand and Sekhon, 1974; Mitra, 1998; and Anandan, 1998 and 1999).
- Calculate the Mean Value Below Zero signal to noise ratios (MVBZ) (Reddy *et al.*, 2008; Harnadth Reddy *et al.*, 2009; and Reddy Harnadth *et al.*, 2010).
- Calculate the Mean Value Above Zero signal to noise ratios (MVAZ) (Reddy *et al.*, 2008; Harnadth Reddy *et al.*, 2009; and Reddy Harnadth *et al.*, 2010).
- Update the value of '~', '£' and '*p*' 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°

where

E_{10y} is East West polarization with off-zenith angle of 10°

W_{10y} is East West polarization with off-zenith angle of 10°

N_{10x} is North South polarization with off-zenith angle of 10°

S_{10x} is North South polarization with off-zenith angle of 10°

Table 1: Specifications of MST Radar	
Period of Observation	July 2011
Pulse Width	16 μs
Range Resolution	150 m
Inter Pulse Period	1000 μs
Number of Beams	6(E_{10y}, W_{10y}, N_{10x}, S_{10x}, Z_x, Z_y)
Number of FFT Points	512
No. of Incoherent Integrations	1
Maximum Doppler Frequency	3.9 Hz
Maximum Doppler Velocity	10.94 m/s
Frequency Resolution	0.061 Hz

RESULTS

The comparison of Planck-Bessel, 3Cosh and Kaiser Window functions in terms of MVBZ SNR and MVAZ SNR of six directions of MST radar as shown in Table 2.

The performance analysis of Planck-Bessel, 3Cosh and Kaiser Window functions for different parameters (~ = 1 to ~:= 10) in terms of CG, ICG, ENBW and SL as shown in Tables 3 to 5.

Table 2: Comparison of Window Functions in Terms of MVBZ SNR and MVAZ SNR for ~:= 6

Window Function/Performance	Planck-Bessel Window £ = 0.1	3Cosh Window *p* = 0.7	Kaiser Window
MVAZ East Beam	9.2649	10.2283	9.0227
MVBZ East Beam	–7.1512	–8.9152	–7.4579
MVAZ West Beam	9.8757	9.6235	9.8173
MVBZ West Beam	–7.1461	–9.2075	–7.4008
MVAZ North Beam	12.3345	12.5328	11.9854
MVBZ North Beam	–8.5226	–10.6205	–9.0491
MVAZ South Beam	11.1723	12.4667	11.4509
MVBZ South Beam	–7.7530	–8.5554	–7.7165
MVAZ Zenith-X Beam	12.2950	12.6395	12.5056
MVBZ Zenith-X Beam	–8.0051	–9.2074	–7.9345
MVAZ Zenith-Y Beam	14.3926	14.4332	14.3362
MVBZ Zenith-Y Beam	–7.5074	–9.0734	–7.7180

Table 3: Performance of Planck-Bessel Window

Shape Parameter ~	Planck-Bessel Window			
	CG	ICG	ENBW	SL
1	0.8271	0.7483	1.0937	0.7182
2	0.7308	0.6142	1.1502	0.7508
3	0.6462	0.5148	1.2326	0.7835
4	0.5816	0.4479	1.324	0.8106
5	0.5317	0.4006	1.417	0.8325
6	0.492	0.3653	1.5091	0.8502
7	0.4595	0.3377	1.5995	0.8648
8	0.4324	0.3156	1.6879	0.877
9	0.4093	0.2972	1.774	0.8874
10	0.3894	0.2817	1.8575	0.8963

Table 4: Performance of 3Cosh Window

Shape Parameter ~	3Cosh Window			
	CG	ICG	ENBW	SL
1	0.9011	0.8209	1.0109	0.6685
2	0.8158	0.6946	1.0437	0.7006
3	0.7574	0.6212	1.0829	0.725
4	0.7149	0.5731	1.1214	0.7437
5	0.6819	0.5382	1.1575	0.7588
6	0.655	0.5111	1.1914	0.7712
7	0.6322	0.4889	1.2232	0.7819
8	0.6125	0.4702	1.2534	0.7912
9	0.5951	0.4541	1.2822	0.7994
10	0.5796	0.44	1.3097	0.8068

Table 5: Performance of Kaiser Window

Shape Parameter ~	Kaiser Window			
	CG	ICG	ENBW	SL
1	0.928	0.8651	1.0047	0.6576
2	0.7948	0.6618	1.0476	0.7038
3	0.6832	0.5311	1.1377	0.7506
4	0.6026	0.4534	1.2485	0.7888
5	0.5438	0.4026	1.3613	0.8183
6	0.4991	0.3660	1.4695	0.8410
7	0.4637	0.338	1.572	0.8589
8	0.4349	0.3157	1.669	0.8732
9	0.4108	0.2972	1.761	0.885
10	0.3904	0.2817	1.8487	0.8947

Figure 1: Variation of CG and ICG-Planck-Bessel Window

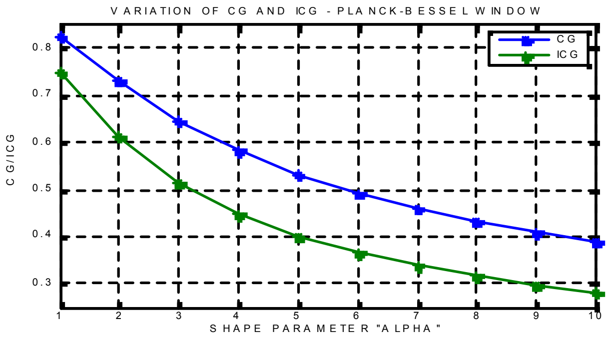


Figure 2: Variation of ENBW and SL-Planck-Bessel Window

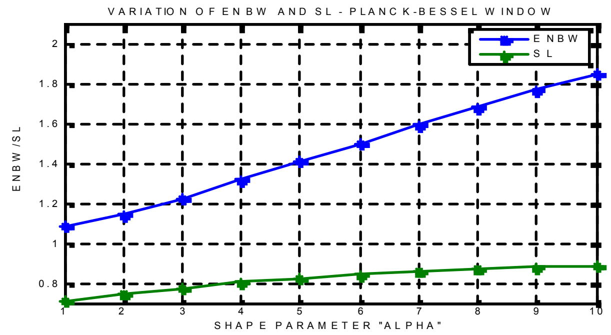


Figure 3: Variation of CG and ICG-3Cosh Window

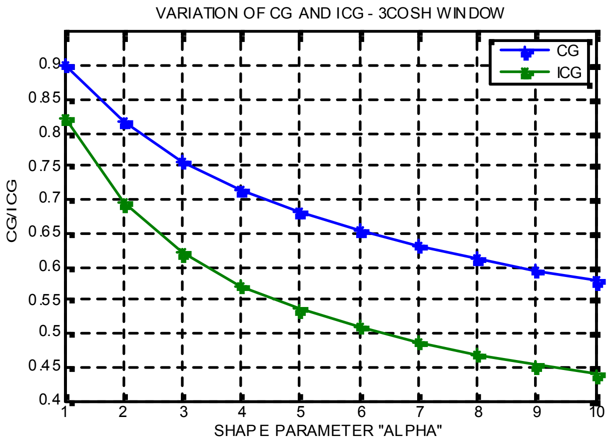


Figure 4: Variation of ENBW and SL-3Cosh Window

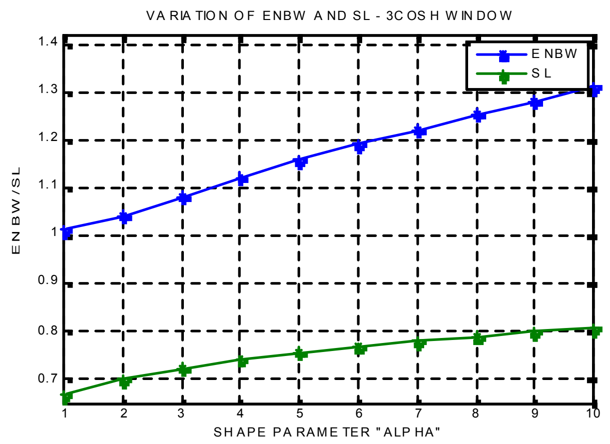


Figure 5: Variation of CG and ICG-Kaiser Window

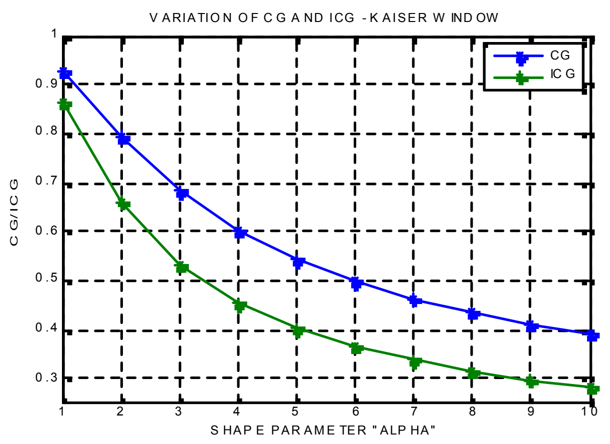
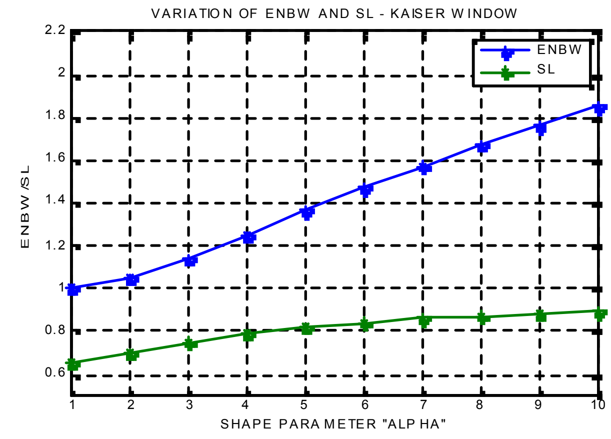


Figure 6: Variation of ENBW and SL-Kaiser Window



The performance variation in CG/ICG and ENBW/SL due to increase in adjustable parameters for Planck-Bessel window shown in Figures 1 and 2, 3Cosh Window shown in Figures 3 and 4 and Kaiser Window shown in Figures 5 and 6.

CONCLUSION

The SNR values for the six sets of MST radar data and performance analysis of Window functions is computed. The MVBZ SNR in all the cases increases with adjustable parameters (~, £ and *p*). The increase in MVBZ continues up to a certain value of the adjustable 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 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 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 parameters plays an important role.

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