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SNR Improvement of MST radar signals by 3COSH Window over Kaiser Window

D.Ravi Krishna Reddy[1], Dr.B.Anuradha[2]

[1] Research Student, Dept.of ECE, S.V.U College of Engineering Tirupati, Andhra Pradesh, India

[2] Professor, Dept.of ECE, S.V.U College of Engineering Tirupati, Andhra Pradesh, India

Abstract: In this paper window shape parameter "α" in Kaiser and 3COSH Window functions on the signal to noise ratio (SNR) values of MST radar is compared. The six sets of multibeam observations made by the Indian Mesosphere-Stratosphere-Troposphere (MST) radar in lower atmosphere are analyzed for results. The echo samples of the in-phase and quadrature components of radar in Fourier transformation are weighted with new version of adjustable windows. The effects of data weighting with the variation of the window shape parameter "α" of the 3COSH and Kaiser Window functions are presented. It is observed that this report is with a good improvement, with an increase of "α" increases the signal to noise ratio values. For 3COSH and Kaiser Window functions are proposed to analyse the MST radar return signals to obtain optimum values of the shape parameter "α". Due to the effect of side lobe reduction, the results shows the improvement of signal to noise ratio of noisy data and demands for the design of optimal window functions.

Keywords: Kaiser Window, 3COSH Window, SNR, DFT, Spectral Analysis.

1. INTRODUCTION

The discrete Fourier transform (DFT) in Harmonic analysis plays a major role in radar signal processing. The significance of using data weighting windows with the DFT [2, 4, 7] plays an important role in resolving the frequency components of the signal buried under the noise. The appropriate window provides the corruption of the principal spectral parameters, hence it is ordered to consider criteria by the choice of data weighting window is used and made [8]. This paper provides the effects of "α" for Kaiser and 3COSH window functions [1], [6] on the signal to noise ratio of radar signals where the 3COSH Window is set at a cost function "p".

2. DATA WEIGHTING WINDOWS

(A) Windowing

Windows are time-domain weighting functions that are used to reduce Gibbs' oscillations resulting from the truncation of a Fourier series [5]. Their roots date back over one-hundred years to Fejer's averaging technique for a truncated Fourier series and they are employed in a variety of traditional signal processing applications including power spectral estimation, beam forming and digital filter design. Windows have been employed to aid in the classification of cosmic data [28], [29] and to improve the reliability of weather prediction models [9].

The application of FFT to a finite length data provides the leakage and picket fence effects. Balancing the data with their appropriate windows [2] can reduce these effects. The use of the data windows other than the rectangular window affects the bias, variance and frequency resolution of the spectral estimations [4, 7]. It is estimated that the

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number of observations are increased if the bias and variance tends to zero. Thus the effect with the spectral estimation of a finite length data by the FFT techniques is the effect of providing efficient data windows or data smoothing schemes .Data windows are used to weight time series of the in-phase and quadrature 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 [2].

(B) Spectral Leakage

The signal frequencies through rectangular window do not correspond exactly to one of the sampling frequencies and the patterns are shifted to non-zero values and are projected to sampling frequencies. The phenomenon of spreading signal power from the nominal frequency across the entire width of the spectrum is known as spectral leakage [2, 10-11]. The data windowing effect on the signal to noise ratio improvement of MST radar signals are reported in literature [12-15, 20-21]. By choosing the suitable values of shape parameters of adjustable windows, it is easy to provide signal to noise ratio improvement with the optimum shape parameters [13-15, 20-21].

Based on the applications the best window depends and these are called as suboptimal solutions. Windows are classified as fixed or adjustable [3]. Fixed windows consist of one independent parameter namely the window length which controls the main-lobe width. Adjustable windows have two or more independent parameters, that parameters control other window characteristics as the window length in fixed windows [2, 22, 24-26]. The Kaiser and Saramaki windows [1, 22] consist of two parameters and provide close approximations to prolate discrete function to analyse the maximum energy concentration in main lobe. The Dolph-Chebyshev window [24], [26] consists of two parameters and provides the minimum main-lobe width for maximum side-lobe level. For various applications the spectral parameters 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 such as Dolph-Chebyshev [26] and Saramaki [3] are special cases of ultra spherical window [23], which performs higher side lobe roll-off characteristics and the same main lobe width can used for Kaiser window.

The quasi-monotonic (atmospheric) signal is superimposed on the background of white noise which is composed by the atmospheric radar. The signal does not correspond exactly to one of sampling frequencies and the signal portions of the spectra envelopes of the side lobe maxima. Therefore the spectral leakage from the signal exceeds noise level determined by the method of Hildebrand and Sekhon [16], and its response to underestimate signal-to-noise ratio.

Based on the shape parameter of Kaiser and 3COSH window functions [1] & [6] on the SNR of radar signals where the 3COSH window is set at a cost function "p" .Compare to Kaiser Window the advantage of 3COSH window is to reduce the computational cost and also it provides higher side lobe roll-off ratio which is useful in the improvement in SNR of MST radar return signals.

3. Characterization of Windows

(A) Kaiser Window

Among the optimum windows Kaiser Window is one of the most useful windows which provide a large main lobe width for attenuation of stop band, which provides the transition width very sharply [27]. The

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trade-off between the main lobe width and side lobe area is quantified by seeking the window function and it is maximally concentrated around the frequency domain of w=0 [7].

$$I_0(x) = 1 + \sum_{k=1}^{\infty}\left[\frac{1}{k!}\left(\frac{x}{2}\right)^k\right]^2 \qquad (1)$$

In discrete time domain, Kaiser Window is defined by [1]

$$w_k(n) = \begin{cases} \dfrac{I_o\left(\alpha\sqrt{1-\left(\frac{2n}{N-1}\right)^2}\right)}{I_o(\alpha)}, & |n| \le \frac{N-1}{2} \\ 0, & otherwise \end{cases} \qquad (2)$$

Where α is the shape parameter of the window, N is the length of window and $I_0(x)$ is the modified Bessel function of the first kind of order zero.

(B) 3COSH Window

This new window is based on the cosine hyperbolic window function that is optimized by applying a cost function for diminishing ripple ratio. Due to this optimization a change is caused in the power of exponential phrases and making a new α function, the adjustable shape parameter, for which the changes can be shown as

$$\cosh(x) = \frac{e^{x^p} + e^{-x^p}}{2} \qquad (3)$$

Using the above the cosine hyperbolic function, the new modified 3COSH window is defined as

$$w_c(n) = \begin{cases} \dfrac{\cosh\left[\alpha\sqrt{1-\left(\frac{2n}{N-1}\right)^2}\right]^p}{\cosh(\alpha^p)}, & |n| \le \frac{N-1}{2} \\ 0, & otherwise \end{cases} \qquad (4)$$

The three parameters like length of the sequence N, a shape parameter "α" and a cost function "p" are useful to get the desired amplitude response pattern of the above windows. The number of FFT points considered in the MST radar data of each range bin is fixed to 512. Hence the window shape parameter "α" and a cost function "p" can be varied to achieve the desired pattern of the magnitude response of the window used. As the shape parameter "α" and a cost function "p" increases, the level of side lobe and the magnitude response decreases at the cost of main lobe width [2],[4]. The SNR variation of MST radar data as a function of the shape parameter "α" and a cost function "p" with respect to side lobe level and main lobe width variations are investigated in this paper.

For the results of SNR improvement of the MST radar data are determined in terms of Mean Value Below Zero (MVBZ) signal to noise ratio and Mean Value Above Zero (MVAZ) signal to noise ratio [14]-[21] for 3COSH and Kaiser Window functions are presented in figures (1) and (2).

4. Windows 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 stratified or turbulent. The atmospheric layer which is a back-scattered signal is very small in terms of power with which it was emitted. The received back-scattered signals also called as radar returns and it is formed with Gaussian noise and that noise dominates the signal as the distance between the radar and the target increases and it leads to decrease in signal to noise ratio. Hence the detection of the signal is difficult. The information on Doppler profile is formed from the power spectrum using Fast Fourier Transform. The back-scattered signals of the radar from the frequency characteristics are analyzed with power spectrum. It specifies the spectral characteristics of frequency domain signals. The specifications of the data are given in Table 1. The analysis of SNR on MST radar provides the data and it corresponds to the lower stratosphere obtained from the NARL, Gadanki, India. The operation of radar was perform in Zenith-X, Zenith-Y, North, South, West and East direction in vertical direction of an angle of 10^o. From the six directions of data are obtained and used

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to carry on the analysis. The algorithm which is represented below provides the use of MATLAB to study the effect of shape parameter “α” and cost function “p” on the SNR radar returns.

Algorithm

- Obtain the 3COSH and Kaiser Window functions with the specified “α” and cost function“p”
- Taper the radar data with Kaiser and 3COSH window weights for specified “α” and cost function“p”
- Compute the Fourier analysis of the above tapered data [17], [19].
- Determine the signal to noise ratio using the procedure [16],[17]
- Calculate the Mean Value below Zero signals to noise ratios (MVBZ)
- Calculate the Mean Value above Zero signals to noise ratios (MVAZ)
- Update the value of “α” and cost function “p” repeat above steps except first step

5. Results

The computation on SNR [16-19] for the radar data which consists of six sets is carried out and presented in figures (1) and (2). The mean value below zero (MVBZ) signal to noise ratio in all the cases increases with the shape parameter “α” and a cost function “p”. The increase in MVBZ continues up to certain value of the shape parameter and a cost function now onwards called optimum “α” and “p” value. Further increase in the shape parameter “α” and a cost function “p”, no appreciable change in MVBZ signal to noise ratio is observed. It is clearly observed that even the change in side lobe reduction contributes to the signal to noise ratio improvement at the cost of main lobe width and it shows the improvement in signal to noise ratio. By increasing the shape parameter “α” and a cost function “p” value there is decrease in side lobe level. But due to the increase in the main lobe width compensates the increase in the MVBZ signal to noise ratio.Therfore the MVBZ signal to noise ratio value attains almost constant of all the six sets of radar data. With side lobe attenuation “α” and a cost function “p” the mean value above zero (MVAZ) signal to noise ratio in all six-sets of radar data there is no appreciable change. Therefore in achieving a good signal to noise ratio improvement, the selection of the shape parameter and a cost function plays an important role. By observing the two windows with same shape parameter “α”, it is proved that the 3COSH Window performs better result than the Kaiser window and this performance is presented in the Table 2. It is observed that the 3COSH Window is found as a computational advantage over Kaiser Window. This Kaiser Window has the disadvantage of power series expansion in its time domain function. Among all the above observations, it is concluded that the 3COSH window can be used to taper the radar data for better analysis of spectral data whenever the application of Kaiser Windows are found. Hence the results also mention that of these side lobe reduction effects, the improvement of SNR of noisy data for the design of optimal window demands.

The MST radar data is used for the computation of mean signal to noise ratio due to the scattering of signals from the lower stratosphere (up to 30 Km) as given below.

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

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Pulse Width : 16µsec

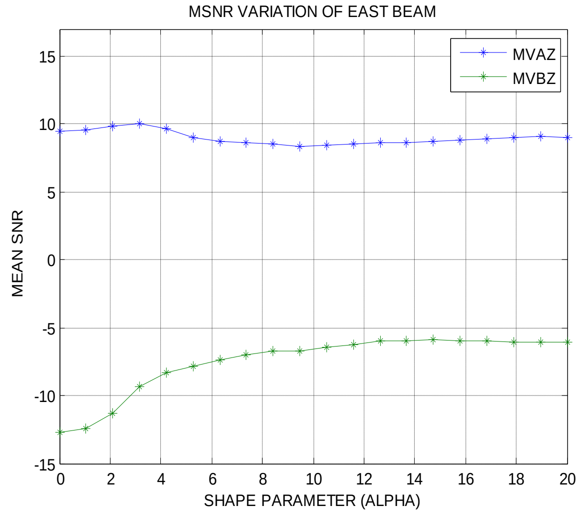
Beam : 10^0

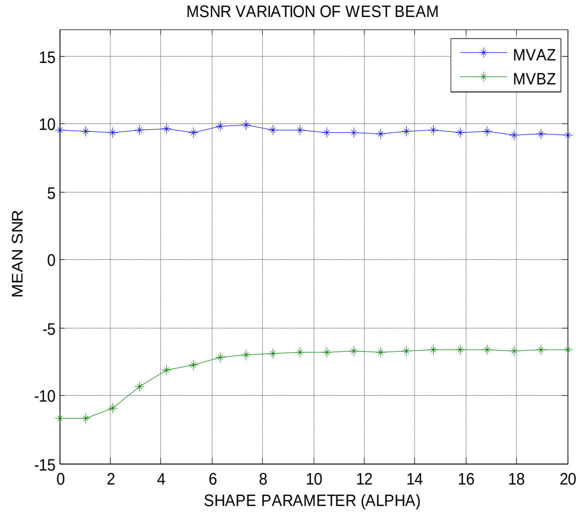
Table 1

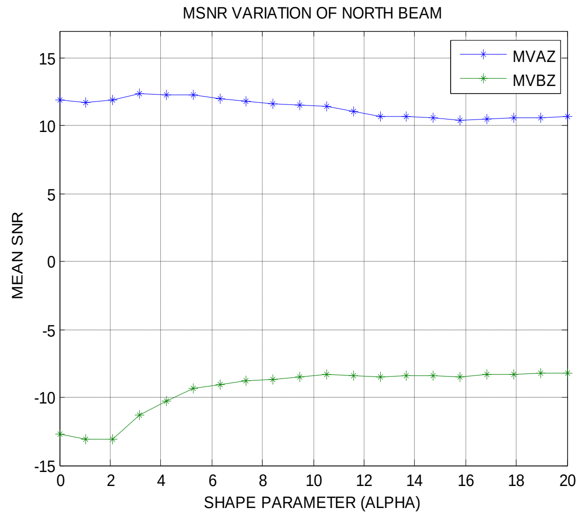
Specifications of MST radar

Period of Observation	July2011
Pulse Width	16 µs
Range resolution	150 m
Inter Pulse Period	1000 µs
No of Beams	6 (E_{10y}, W_{10y}, Z_y, Z_x, N_{10x}, S_{10x})
No 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
Where E_{10y}=East West polarization with off-zenith angle of 10^0 W_{10y}=East West polarization with off-zenith angle of 10^0 N_{10x}=North South polarization with off-zenith angle of 10^0 S_{10x} = North South polarization with off-zenith angle of 10^0	

Average SNR of radar data for two different windows as shown in figures (1) and (2)







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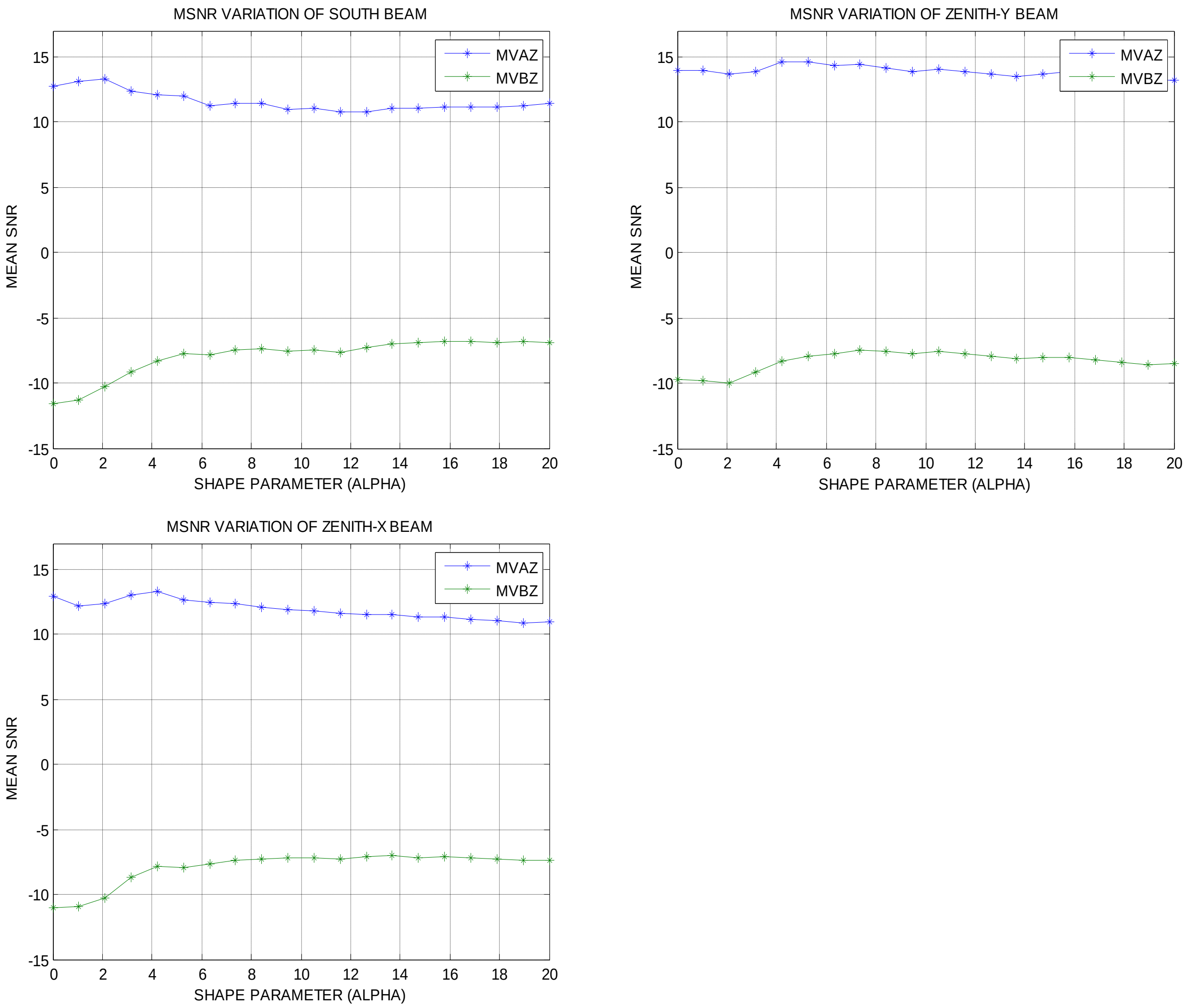

Fig.(1) Average SNR of the Radar data (Six Sets) collected from NARL, Gadanki, INDIA using "KAISERWINDOW"

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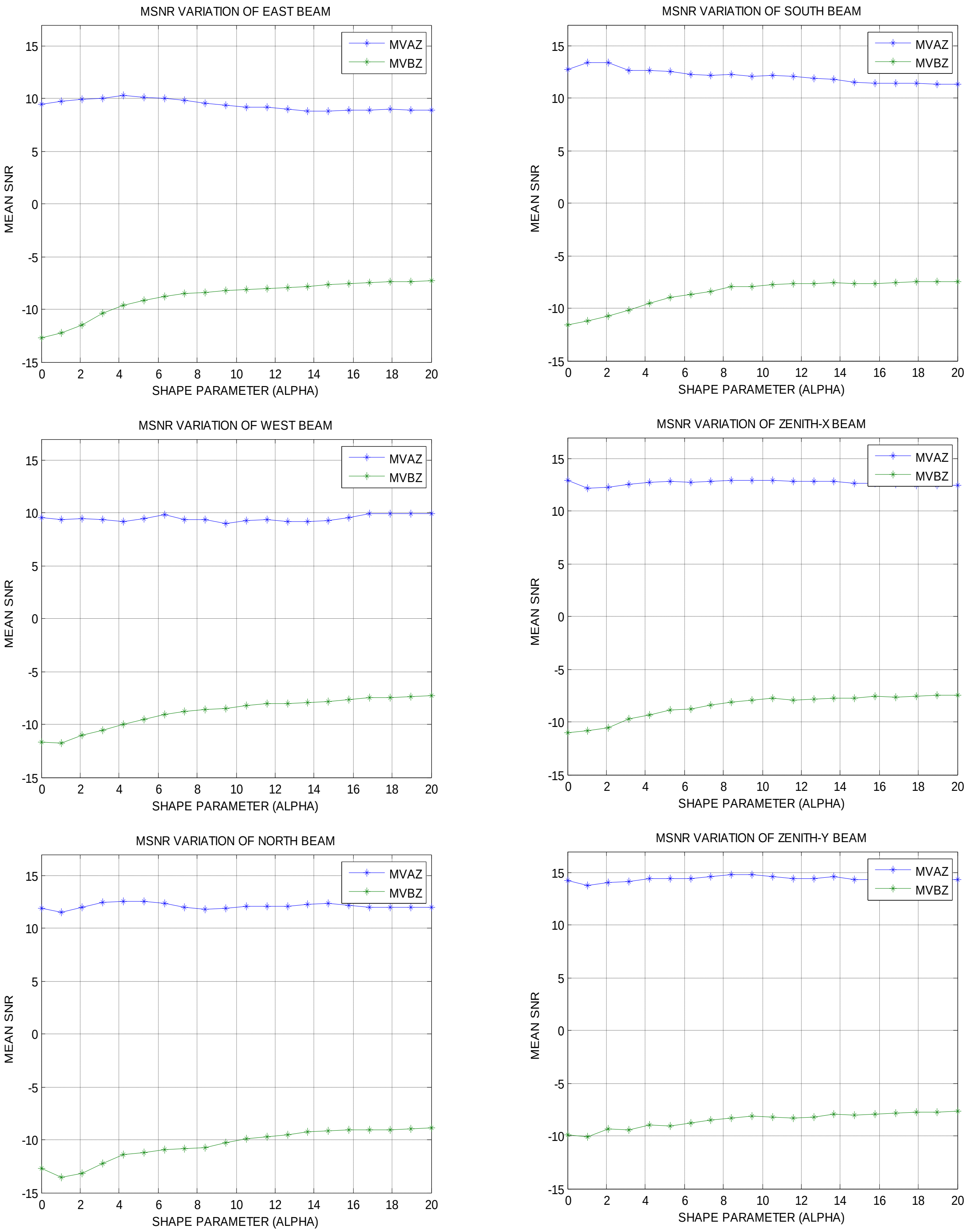

Fig.(2) Average SNR of the Radar data (Six Sets) collected from NARL, Gadanki, INDIA using "3COSH WINDOW"

Table 2

Comparison of MVBZ signal to noise ratio and MVAZ signal to noise ratio values for two windows

Beam	Kaiser Window α=12		3COSH Window α=12 & p=0.7	
	MVBZ	MVAZ	MVBZ	MVAZ
East	-6.0393	9.0178	-7.9815	9.1572
West	-6.5675	9.3699	-7.6801	9.4270
North	-7.6149	10.8694	-9.0633	12.1548
South	-6.1619	10.8259	-7.0152	12.0831
Zenith-X	-6.6270	11.5785	-7.7164	12.8089
Zenith-Y	-6.4676	13.7764	-7.4133	14.3996

6. CONCLUSION

In this paper, 3COSH window is analysed and compared with Kaiser Window function. The 3COSH window has been derived in the same way of the derivation of Kaiser Window but it has the advantage of having no power series expansion in its time domain function. But Kaiser Window provides better ripple ratio as compared to the cosh window. This disadvantage can be overcome by the combination of hamming window with cosh window. Further the complexity can be reduced by introducing a modified window having a new adjustable parameter, that also increases the main lobe width and reduces the side lobe ratio and ripple ratio.

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