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# Improved SNR of MST RADAR Signals by Cosine Hyperbolic Window over Kaiser Window

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**Abstract–In this paper, the effect of window shape parameter "α" in Cosine Hyperbolic Window Function on the SNR values of MST RADAR returns has been investigated. Six sets of multibeam observations of the lower atmosphere made by the Indian Mesosphere-Stratosphere-Troposphere (MST) RADAR are used for the result analysis. Prior to the Fourier Transformation, the in-phase and quadrature components of the RADAR echo samples are weighted with the recently proposed new class of adjustable window based on the Cosine Hyperbolic Window Function. The effects of data weighting with the variation of the window shape parameter "α" of the Cosine Hyperbolic Window Function is presented. It is observed that the increase of "α" increases the SNR values and a good improvement is reported. Optimum value of the shape parameter "α" for the Cosine Hyperbolic Window Function is suggested to analyze the MST RADAR signals. The results also shows that, the improvement of SNR of noisy data due to the effect of side lobe reduction and demands for the design of optimal windows.**

**Keywords–Cosine Hyperbolic Window Function, DFT, FFT, SNR, Spectral Analysis.**

## I. Introduction

Harmonic analysis with the Discrete Fourier Transform (DFT) plays a central role in Radar Signal Processing. The significance of using data weighting windows with the DFT [1]-[3] plays an important role in resolving the frequency components of the signal buried under the noise. Since the use of an inappropriate window can lead to corruption of the principal spectral parameters, hence it is instructive to consider the criteria by which the choice of data weighting window to be used is made [4]. This paper presents the effects of "α" in recently proposed new class of adjustable window based on the Cosine Hyperbolic Window Function [5]-[6] on the SNR of Radar returns and proposed an optimum value of "α" with which data may be weighed using the Cosine Hyperbolic Window Function.

## II. The Data Weighting Windows

There are many types of data weighting windows, which are used to select finite number of samples of impulse response.

### *A. Windowing*

Windows are time-domain weighting functions that are used to reduce Gibbs' oscillations resulting from the truncation of a Fourier Series [7]. 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 [8]-[9] and to improve the reliability of weather prediction models [10].

It is well known [1]-[3] that the application of FFT to a finite length data gives rise to leakage and picket fence effects. Weighting the data with suitable windows can reduce these effects. However the use of the data windows other than the rectangular window affects the bias, variance and frequency resolution of the spectral estimates [2]-[3]. In general, variance of the estimate increases with the use of a window. An estimate is to be consistent if the bias and the variance both tend to zero as the number of observations are increased. Thus, the problem associated with the spectral estimation of a finite length data by the FFT techniques is the problem of establishing 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 samples prior to applying the DFT. The observed Doppler spectra therefore represent convolutions of the Fourier Transforms of the original signals with those of the data weighting windows projected onto the discrete frequencies [1].

### *B. 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 known as spectral leakage [1], [11]-[12]. The effect of data windowing on the SNR improvement of MST Radar signals has been reported in the literature [13]-[18]. By properly selecting the shape parameters of the adjustable windows, it is made possible to achieve the SNR improvement with the Optimum shape parameters [14]-[18].

In literature many windows have been proposed [1], [19]-[23]. They are known as suboptimal solutions, and the best window is depending on the applications. Windows can be categorized as fixed or adjustable [24]. Fixed windows have only one independent parameter, namely, the window length which controls the main-lobe width. Adjustable windows have two or more independent parameters, namely, the window length, as in fixed windows, and one or more additional parameters that can control other window characteristics [1],[20]-[21],[25]-[26]. The Kaiser and Saramaki windows [19]-[20] have two parameters and achieve close approximations to discrete prolate functions that have maximum energy concentration in the main lobe. The Dolph-Chebyshev window [21],[25] has also two parameters and produces the minimum main-lobe width for a specified maximum side-lobe level. With adjusting their two independent parameters, namely the window length and the shape parameter, it can be controlled the spectral parameters of main lobe width and ripple ratio for various applications. Kaiser window has a better sidelobe roll-off characteristic than the other well known adjustable windows such as Dolph-Chebyshev [21] and Saramaki [24], which are special cases of Ultra-spherical window [23], but obtaining a window which performs higher sidelobe roll-off characteristics for the same main lobe width than Kaiser Window will be useful.

The Atmospheric Radar returns considered to be composed of a quasi-monotonic (atmospheric) signal superimposed on a background of white noise. As might be expected, since the signal does not correspond exactly to one of the sampling frequencies, the forms of the signal portions of the spectra follow those of the envelopes of the side lobe maxima. Spectral leakage from the signal therefore exceeds noise level, evaluated by the method of Hildebrand and Sekhon [27], and a corresponding underestimate of Signal to Noise Ratio.

In this paper, the improvement of SNR of MST Radar signals is investigated based on the shape parameters of newly proposed Cosine Hyperbolic Window Function [5]-[6]. The main advantage of the window is to reduce the computational cost when compared with the Kaiser and Dolph-Chebyshev windows. Also they provide higher side lobe roll-off ratio than Kaiser Window which is useful in the improvement in SNR of MST Radar signals.

## III. Windowing techniques

Windowing techniques are used in FIR filter design, where window function w(n) may be multiplied with infinite samples of impulse response h(n). There are many window functions, namely, Rectangular Window, Hanning Window, Hamming Window, Blackmann Window, Barlett Window and Kaiser Window. Among them popularly used adjustable window is Kaiser Window.

### *A. Kaiser Window*

In discrete time domain, the Kaiser Window is defined by [19]

$$w_k(n,\alpha) = \begin{cases} \dfrac{I_0\left(\alpha\sqrt{1-\left(\dfrac{2n}{N-1}\right)^2}\right)}{I_0(\alpha)}, & |n| \le \dfrac{N-1}{2} \\ 0, & otherwise \end{cases}$$

Where ‘**α**’ is the adjustable shape parameter, and $I_0(x)$ is the modified Bessel function of the first kind of order zero and it is described by the power series expansion as

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

Computation of the Bessel function $I_0(x)$ is some what difficult; because of it has power series expunction.

### *B. The Cosine Hyperbolic Window*

The hyperbolic cosine of x is expressed as [6]

$$Coshx = \frac{e^x + e^{-x}}{2}$$

Using the above the Cosine Hyperbolic Window can be defined as

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

The two parameters useful to obtain the desired amplitude response pattern of the above defined windows are the length of the sequence N and a shape parameter “**α”.** As the number of FFT points considered in the MST Radar data of each range bin is fixed to 512, the window length N is fixed to 512. Hence the shape parameter “**α”** can be only varied to achieve the desired pattern of the magnitude response of the window used.

As the shape parameter“**α”** increases, the side lobe level of the magnitude response decreases at the cost of main lobe width [1-3]. In this paper we have investigated the SNR variation of MST Radar data as a function of the shape parameter “**α”** with respect to side lobe level and main lobe width variations.

The results of SNR improvement of the MST Radar data are evaluated in terms of Mean Value Below Zero (MVBZ) SNR and Mean Value Above Zero (MVAZ) SNR [15]-[18] for Cosine Hyperbolic Window and corresponding graphs are presented in fig.1 and fig.2.

## IV. Windows applied to Atmospheric Radar signals

Wind profile detection of a MST Radar signal meant the measurement of Doppler’s of the signal due to scattering of the atmospheric elements. Atmospheric Radar signal meant the signal received by the Radar due to the back scattering property of the atmospheric layers, stratified or turbulent. The back-scattered signal from the atmospheric layers is very small in terms of power with which it was emitted. The received back-scattered signals otherwise called as Radar returns are associated with Gaussian noise. The noise dominates the signal as the distance between the Radar and the target increases and this leads to a decrease in Signal to Noise Ratio. This makes the detection of the signal difficult. Doppler profile information is obtained from the power spectrum using Fast Fourier Transform. Frequency characteristics of the back-scattered signals of the Radar are analyzed with power spectrum, which specifies the spectral characteristics of a signal in frequency domain.

The specifications of the data are given in table.1. The SNR analysis is performed on MST Radar data corresponds to the lower stratosphere obtained from the NARL, Gadanki, India, on 13th July 2009. The Radar was operated in Zenith X, Zenith Y, North, South, West and East directions with an angle of $10^o$ from the vertical direction. The data obtained from the six directions are used to carry on the analysis. The algorithm presented below, uses MATLAB to study the effect of **"α"** on the SNR of the Radar returns.

## V. ALGORITHM

The implementation scheme to compute mean SNR verses variation in shape parameter "α" is presented.

(a). Compute the Cosine Hyperbolic Window with the specified "**α**"
(b). Taper the Radar data with the window weights specified in (a).
(c). Perform the Fourier analysis of the above tapered data [28]-[30].
(d). Compute the SNR using the procedure [27]-[28]
(e). Compute the Mean Value Below Zero SNR'S (MVBZ)
(f). Compute the Mean Value Above Zero SNR'S (MVAZ)
(g). Up date the value of "**α**" and repeat the steps (b)-(f).

## VI. RESULTS AND CONCLUSION

The SNR computation [27[-[30] for the six sets of Radar data is carried on and presented in fig.1 and fig.2. The Mean Value of Below Zero SNR'S (MVBZ), in all the cases increases with the shape parameter "**α".** The increase in MVBZ continues up to certain value of the shape parameter now onwards called optimum "**α**" value. Further increase in the shape parameter "**α",** no appreciable change in MVBZ SNR is observed.

This fact clearly demonstrates that even if the sidelobe reduction, which contributes the SNR improvement at the cost of main lobe width, shows the improvement in SNR. Further increasing the "**α**" value still decreases the side lobe level but due to the increase in the main lobe width compensates the increase in the MVBZ SNR. Hence the MVBZ SNR value attains almost constant in all the six sets of Radar data. On the other hand in all the six-sets of data, there is no appreciable change in the Mean Value of the Above Zero SNR'S (MVAZ) with sidelobe attenuation "**α**".

These results are important since the back-scattered signal from the middle and uppermost bins are very week and improvement in SNR is highly desirable in spectral estimation. Therefore selection of the shape parameter plays important role in achieving SNR improvement.

From the observations presented in the Table.2 using two windows with same shape parameter"**α",** it is concluded that the Cosine Hyperbolic Window exhibit better performance than the Kaiser window presented here.

On the other hand the Cosine Hyperbolic Window find computational advantage over Kaiser Window, since Kaiser Window has the disadvantage of having power series expansion in its time domain function. Noting the above observations, it is concluded that the Cosine Hyperbolic Window can be used to taper the Radar data for better spectral analysis where ever the Kaiser window finds application. The results also suggest that, the effect of side lobe reduction in the improvement of SNR of noisy data and demands for the design of optimal windows.

The data used in MST RADAR centre, Gadanki, India for the computation of mean SNR 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 |
| Pulse Width | : 16μsec |
| Beam | : $10^{\circ}$ |

TABLE.1
Specifications of the MST RADAR, INDIA data on which the analysis is performed

| **Period of Observation** | **2008-2010** |
|---|---|
| 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 |
| Velocity resolution | 0.176 m/s |

$E_{10y}$: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 $10^0$

TABLE.2
Comparison of MVBZ SNR and MVAZ SNR values for two windows for "α=6"

| **Beam** | **Kaiser Window** | | **Cosine Hyperbolic Window** | |
|---|---|---|---|---|
| | MVBZ | MVAZ | MVBZ | MVAZ |
| East | -7.4469 | 9.0227 | -7.3104 | 8.7237 |
| West | -7.1290 | 9.9494 | -6.8909 | 9.9951 |
| North | -8.5596 | 11.9854 | -8.1785 | 12.2462 |
| South | -6.7901 | 11.4509 | -6.6644 | 11.3258 |
| ZenithX | -7.4145 | 12.5056 | -7.2079 | 12.4634 |
| ZenithY | -6.9176 | 14.3362 | -6.7314 | 14.4070 |

Variation in average SNR of Radar data due to increase in window shape parameter "α" for both Kaiser Window and Cosine Hyperbolic Window shown in Fig.1 and Fig.2.

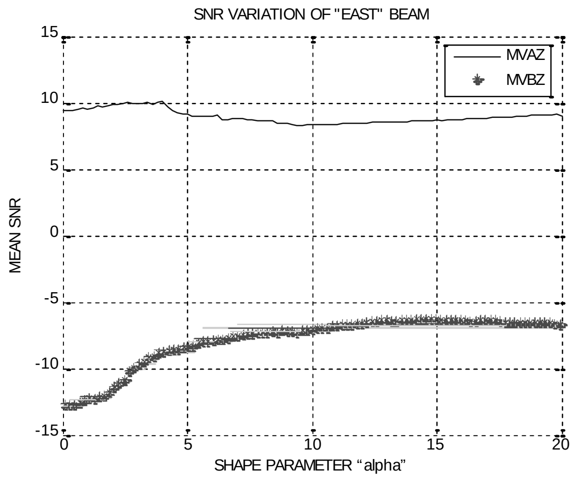


Fig. 1(a)

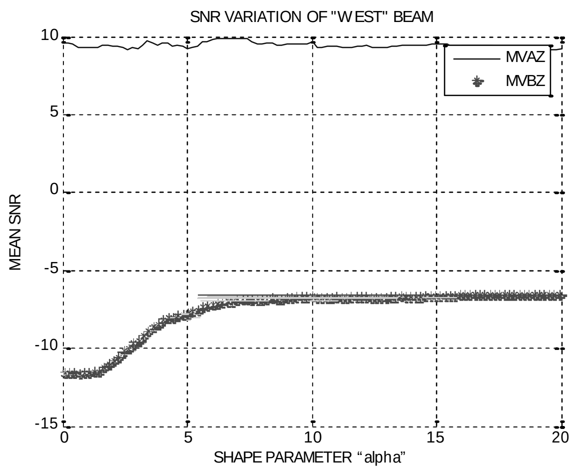


Fig. 1(b)

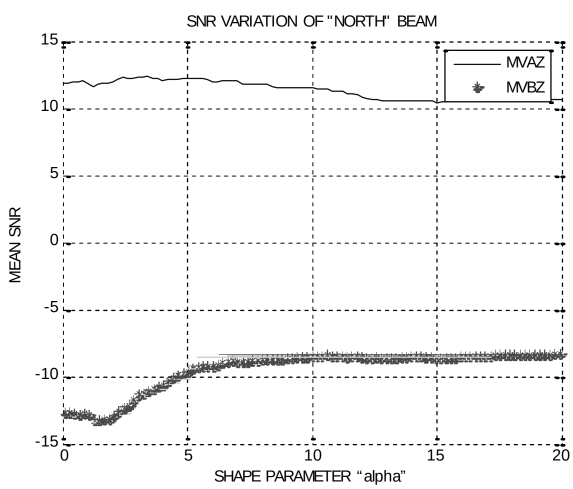


Fig. 1(c)

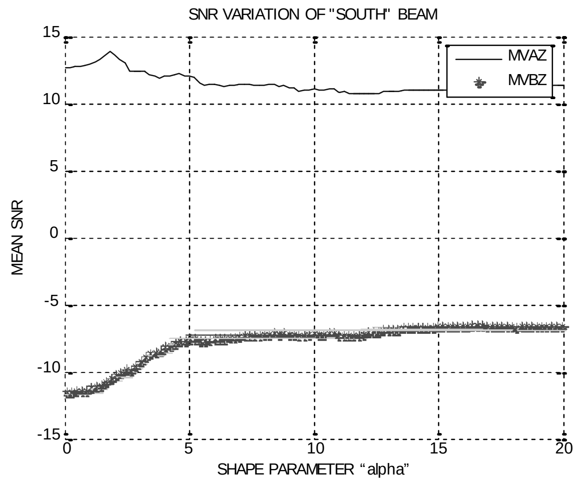


Fig. 1(d)

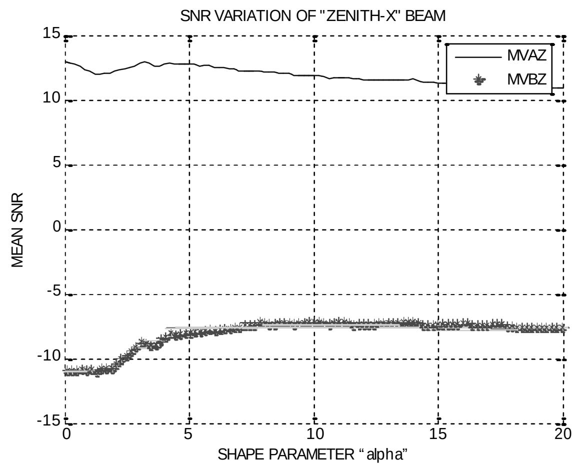


Fig. 1(e)

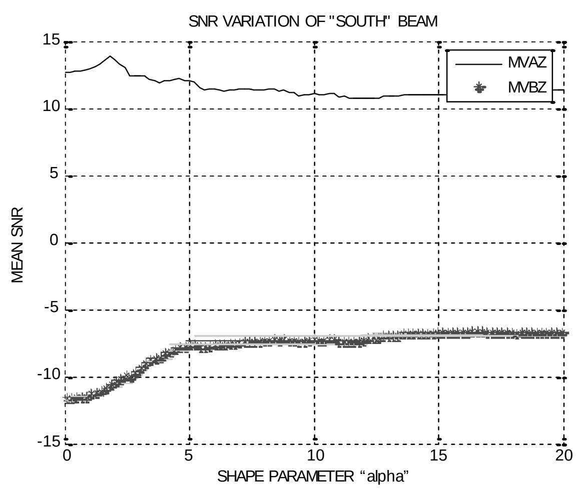


Fig. 1(f)

Fig.1 Average SNR of the RADAR data collected from NARL, Gadanki, INDIA- "KAISER WINDOW"

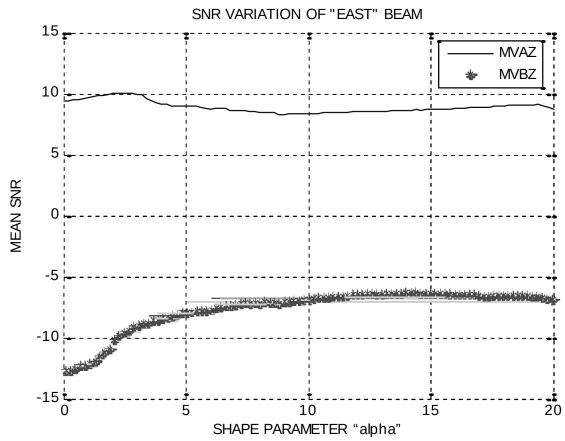


Fig. 2(a)

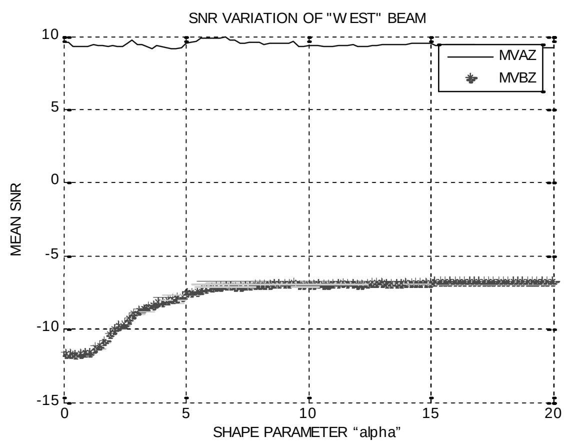


Fig. 2(b)

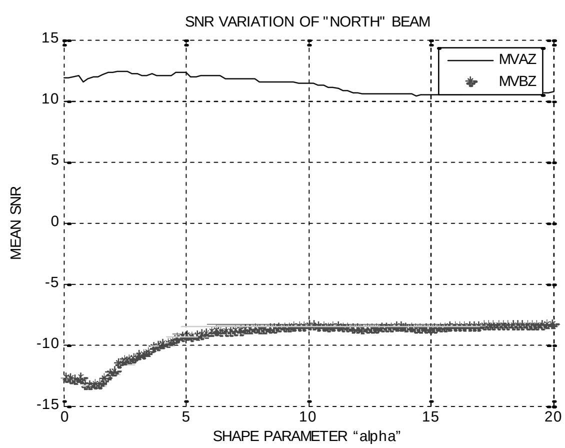


Fig. 2(c)

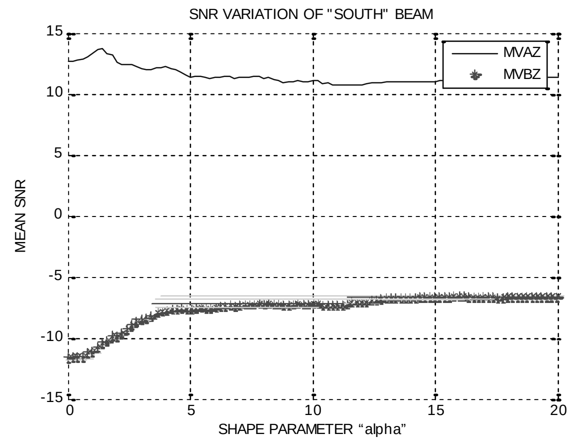


Fig. 2(d)

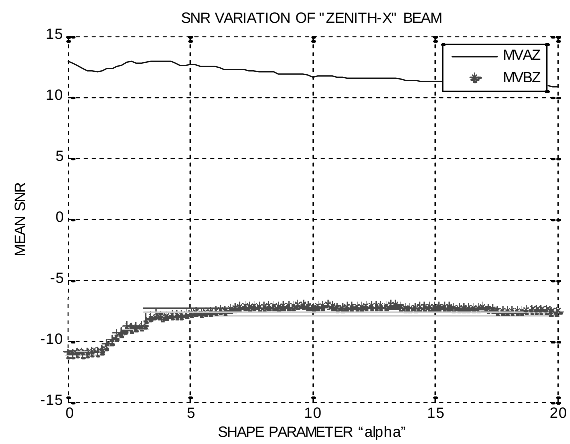


Fig. 2(e)

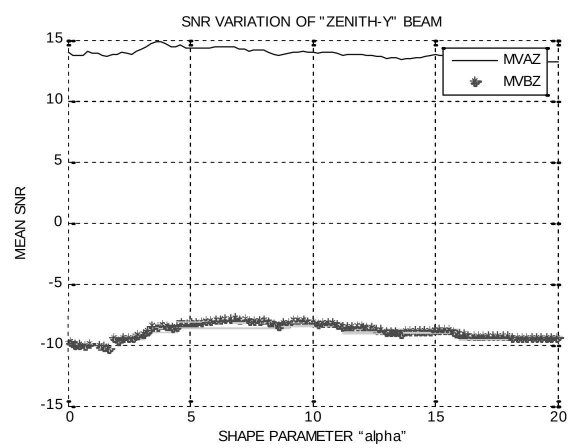


Fig. 2(f)

Fig.2 Average SNR of the RADAR data collected from NARL,Gadanki, INDIA-"COSINE HYPERBOLIC WINDOW"

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