The Effect of Window Parameter (α) in Dolph-chebyshev window on the processing of atmospheric signals

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Abstract: **The effect of Window Parameter (α) in Dolph-Chebyshev window on the SNR of radar returns is discussed and proposed an optimum value of "α" with which data may be weighed using Dolph-Chebyshev window. It is observed that the Dolph-Chebyshev window can be used with "α"corresponding to the minimum of sidelobe attenuation of 50dB to taper the data for spectral analysis. From the results, it may be noted that there is effect of side lobe reduction in the improvement of SNR of noisy data.**

INTRODUCTION

Windows are time-domain weighting functions that are used to reduce Gibbs' oscillations resulting from the truncation of a Fourier series. The conventional method that is adopted is to multiply the data with a rectangular window of the same length as that of the data, finding Discrete Fourier Transform of the multiplied sequence and from this finding the power spectrum. It is well known that the application of FFT to a finite length data gives rise to spectral leakage and picket fence effects. So a window which gives a spectrum that has minimum leakage is preferred. 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. In general, variance of the estimate increases with the use of a window. An estimate is to be consistent if both the bias and the variance tend to zero as the number of observations is 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 complex time series of the in-phase and quadrature 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 (angular) frequencies.

A good survey on windows is reported in the literature [1, 2, 3]. Windows can be categorized as fixed or adjustable [4, 5]. 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 [6]. The Kaiser window has two parameters and achieves close approximations to discrete prolate functions that have maximum energy concentration in the main lobe [7, 8]. The Dolph-Chebyshev window has two parameters and produces the minimum main-lobe width for a specified maximum side-lobe level [7, 9, 10]. The Kaiser and Dolph-Chebyshev windows can control the amplitude of the side lobes relative to that of the main lobe, and through the proper choice of these parameters, the amplitude of the side lobes relative to that of the main lobe can be controlled.

The 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, and a corresponding underestimate of signal-to-noise ratio [10].

WINDOW TECHNIQUE APPLIED TO ATMOSPHERIC RADAR SIGNALS:

Wind profile detection of a MST Radar signal means the measurement of Dopplers of the signal due to scattering of the atmospheric elements. Atmospheric Radar signal is 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.
Since the SNR is not constant and varies from bin to bin, therefore in this study, the window performance on the SNR values of the radar returns, the 150 bin atmospheric data is divided in to Three equal parts. Each part consists of 50 bins viz. LOWER BINS, MIDDLE BINS and UPPER BINS. In each of these three regions the mean value of SNR is computed for the SNRs below zero dB and the SNRs above zero dB. We name them as MVBZ (Mean Value Below Zero) SNR and MVBZ (Mean Value Above Zero)

SNR respectively. The SNR computation is based on the above terminology using the various windows found in the literature and is presented in this work.

THE DOLPH- CHEBYSHEV WINDOW

The optimality criterion addressed by the Dolph- Chebyshev window is that its Fourier transform exhibit the narrowest main-lobe width for a specified (and selectable) side-lobe level[11]. The Fourier transform of this window exhibits equal ripple at the specified side-lobe level. The Fourier Transform of the window is a mapping of the Nth order algebraic Chebyshev polynomial to the N-th order trigonometric Chebyshev polynomial by the relationship $T_N(X)$ = COS(Nq). The Dolph-Chebyshev window is defined in terms of uniformly spaced samples of its Fourier Transform. These samples are defined in [2.6].

$$W(k)=(-1)^k \frac{\cosh\left[N\cosh^{-1}(\beta\cos(\pi\frac{k}{N}))\right]}{\cosh[N\cosh^{-1}(\beta)]} : \quad 0\le k<N-1$$

$$\text{where } \beta \text{ is defined by :}$$

$$\beta=\cosh\left[\frac{1}{N}\cosh^{-1}(10^{\frac{-A}{20}})\right]$$

$$\text{and where A} = \text{Sidelobe level (in dB)}$$

$$w(n)=\sum_{k=0}^{N-1} w(k)e^{j\frac{2\pi}{N}nk} : \quad \text{and where } W(N-k)=W(-k)$$

.... (1)

The Fourier Transform of this window exhibits uniform, or constant level side-lobes levels (inherited from the Chebyshev polynomial) and as such contain impulses in its time series. These impulses are located at the window boundaries. Figures 1 and 2 indicate the time and frequency description of a Dolph-Chebyshev window. The Chebyshev, or equal ripple behavior of the Dolph-Chebyshev window can be obtained iteratively by the Remez (or the Equal-Ripple or Parks-Mclellan) Filter design routine For comparison, Figure.1 presents a window designed as a narrow-band filter with 40 dB side lobes and Figure 2 is 80 dB sidelobes.

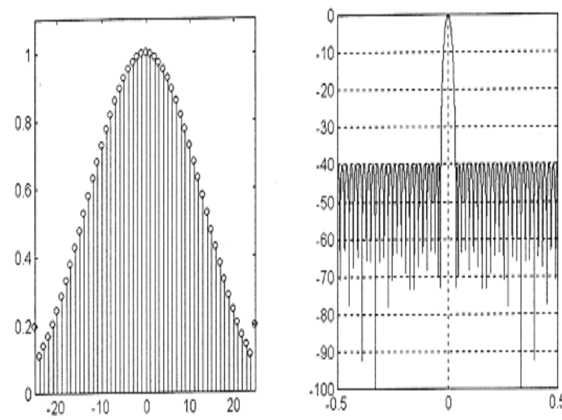

Figure: 1 Dolph-Chebyshev (40dB) window and its Fourier Transform.

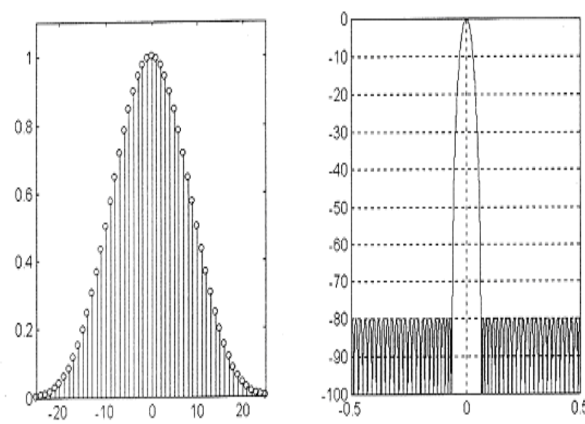

Figure: 2. Dolph-Chebyshev (80dB) window and its Fourier Transform.

Windows (and filters) with constant level side-lobes, while optimal in the sense of equal ripple approximation, are sub-optimal in terms of their integrated side-lobe levels. The window (or filter) is used in spectral analysis to reduce signal bandwidth and then sample rate. The reduction in sample rate causes aliasing. The spectral content in the side-lobes, (the out-of band energy) folds back to the in-band interval and becomes in-band interference. A measure of this unexpected interference is integrated side-lobes, which, for a given main-lobe width, is greater when the side-lobes are equal-ripple. From systems point of view, the window (or filter) should exhibit 6-dB per octave rate of falloff of side-lobe levels. Faster rates of falloff actually increase integrated side-lobe levels due to an accompanying increase in close-in side-lobes as the remote side-lobes are depressed (while holding main-lobe width and window length fixed).

To obtain the corresponding window time samples w(n), we simply perform the DFT on the samples W(k) and then scale for unity peak amplitude.

The parameter "α" represents the logarithm of the ratio of main-lobe level to sidelobe level. Thus a value of "α" equal to 3.0 represents sidelobes 3.0 decades down from the main lobe, or sidelobes 40.0 dB below the main lobe. In this chapter the variation of SNR is considered as a function of side lobe attenuation in dB (i.e."α" in dB). The $(-1)^k$ alternates the sign of successive transform samples to reflect the shifted origin in the time domain.

In contrast to the other windows, the Dolph-Chebyshev window has two parameters: the length of the sequence N and a shape parameter "α". As the length of the window is fixed to 512 data points in case of MST Radar data used, the shape parameter "α" can be varied. As the parameter increases the side lobe level of the frequency response decreases. In this chapter, the SNR variation of MST radar data as a function of side lobe attenuation has been investigated.

DOLPH - CHEBYSHEV WINDOW APPLIED TO ATMOSPHERIC RADAR SIGNALS:

The specifications of the data selected given in Table.1. The SNR analysis is performed on MST Radar data corresponds to the lower stratosphere obtained from the NARL, Gadanki, India. The Radar was operated in Zenith X, Zenith Y, North, South, West and East with an angle of 10° from the vertical direction. The data obtained from the six directions are used to carry on the analysis. The computation using Dolph-Chebyshev window is done to study of the effect of "α" on the SNR of the radar returns.

Lower Stratosphere (up to 30 Km) -MST RADAR, Gadanki, India

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°

Period of Observation	**July 2008**
Pulse Width	16 μs
Range resolution	150 m
Inter Pulse Period	1000 μs
No of Beams	6 (E10y, W10y, Zy, Zx, N10x, S10x)
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

Table 1 Specifications of the MST Radar, India data on which the analysis is performed.

E10y = East West polarization with off-zenith angle of 10^0

W10y = East West polarization with off-zenith angle of 10^0

N10x = North South polarization with off-zenith angle of 10^0

S10x = North South polarization with off-zenith angle of 10^0

The implementation scheme is presented here.

a) Compute the Dolph-Chebyshev window with specified α.

b) Taper the radar data with the Dolph-Chebyshev window parameters specified.

c) Perform the Fourier analysis of the above tapered data.

d) Compute the SNR

e) Compute the Mean Value Below Zero SNRs (MVBZ)

f) Compute the Mean Value Above Zero SNRs (MVAZ)

g) Up date the value of α and repeat the steps (b)-(f).

RESULTS AND DISCUSSION:

The SNR computation discussed above for the six sets of Radar data is carried on and presented in Figures 3(a)-(f) and Figures 4(a)-(f). From Figures 3(a)-(f), in the case of East beam,SNRs (MVBZ) for the entire 150 bins taken into account, increases with the sidelobe attenuation factor "α". But in the case of West, North and South beams there is no appreciable change observed. In the case of Zenith-X and Zenith-Y beams, MVBZ increases with the sidelobe attenuation of 20-30dB and decreases beyond 30dB. This may be attributed to the fact that the generation mechanism of the zenith beams is different [42]. On the other hand in all the Six-sets of data, the Mean value of the Above zero SNRs (MVAZ) increases with sidelobe attenuation "α". It attains a steady value when "α" is in between 60-70dB.

From the Figures 3(a)-(f) it is also observed that for the lowermost 50 bins, the MVBZ and MVAZ are not improved appreciably. Moreover, a slight and marginal decrease in both SNR's is observed. For the middle 50bins and the uppermost 50 bins the increase in MVBZ values is almost 3dB - 9dB when sidelobe attenuation "α" reaches a value around 50dB-60dB. Further slight improvement is also seen when "α" is increased beyond 60dB. This result is important since the back-scattered signal from the middle and uppermost bins is very weak and improvement in SNR demands for the design of windows with good sidelobe behaviour for spectral estimation.

Noting the above observations, it is concluded that the Dolph-Chebyshev window can be used with "α"corresponding to the minimum of sidelobe attenuation of 50dB to taper the data for spectral analysis. The results also suggest that there is effect of side lobe reduction in the improvement of SNR of noisy data and the design of optimal windows.

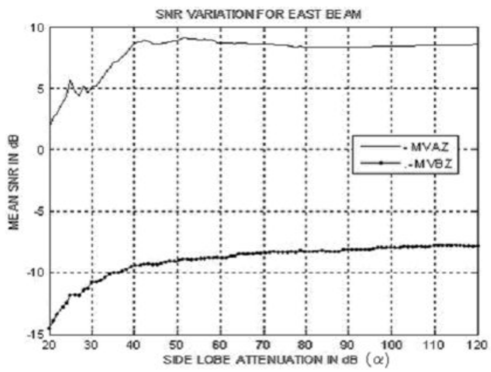

Figure.3(a): AVERAGE SNR EAST Beam

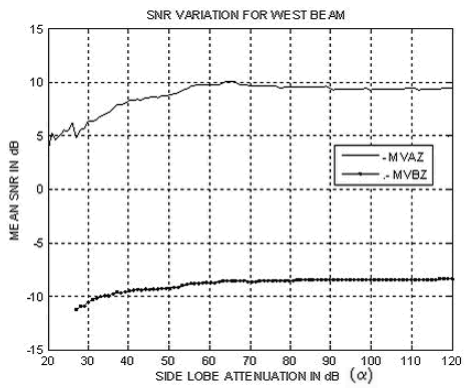

Figure.3(b): AVERAGE SNR WEST Beam

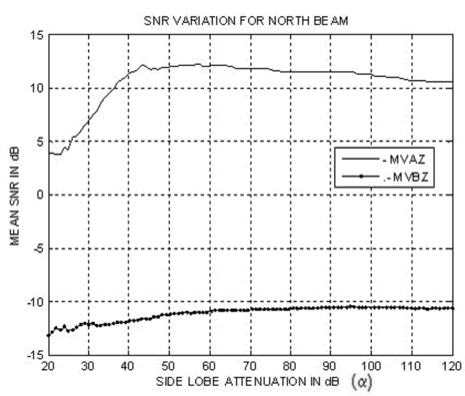

Figure.3(c): AVERAGE SNR NORTH Beam

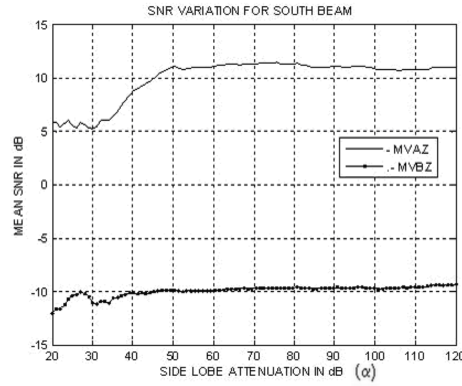

Figure.3(d): AVERAGE SNR SOUTH Beam

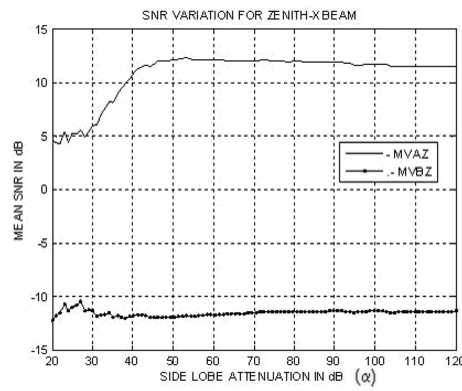

Figure.3(e): AVERAGE SNR ZENITH-X Beam

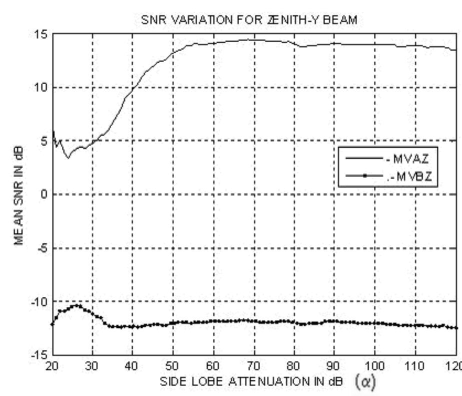

Figure.3(f): AVERAGE SNR ZENITH-Y Beam

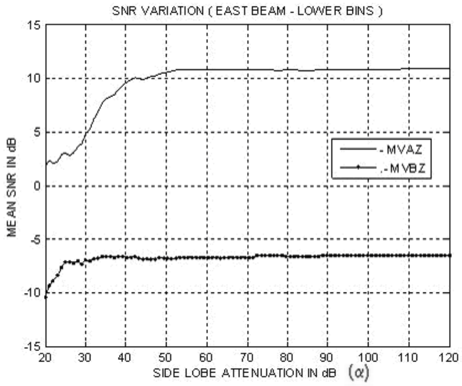

Figure.4(a)(i): AVERAGE SNR Lower Bins - East Beam

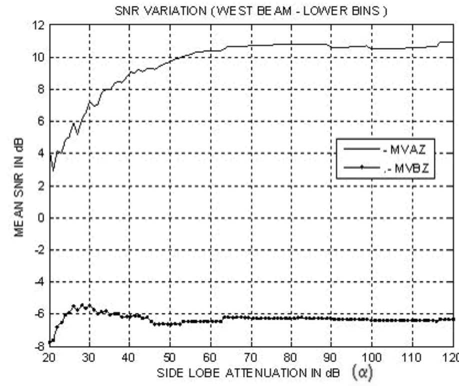

Figure.4(b)(i): AVERAGE SNR Lower Bins - West Beam

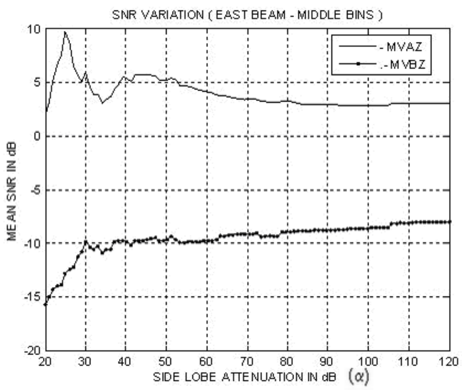

Figure.4(a)(ii): AVERAGE SNR Middle Bins - East Beam

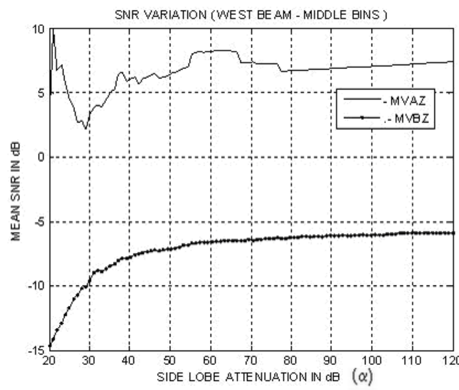

Figure.4(b)(ii): AVERAGE SNR Middle Bins - West Beam

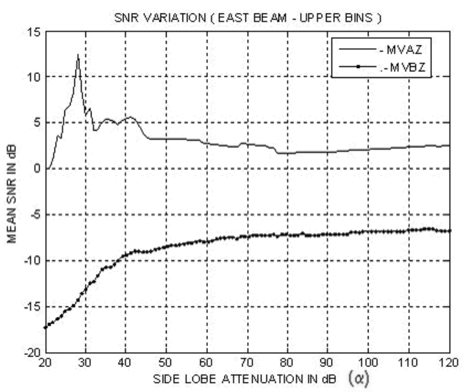

Figure.4(a)(iii): AVERAGE SNR Upper Bins - East Beam

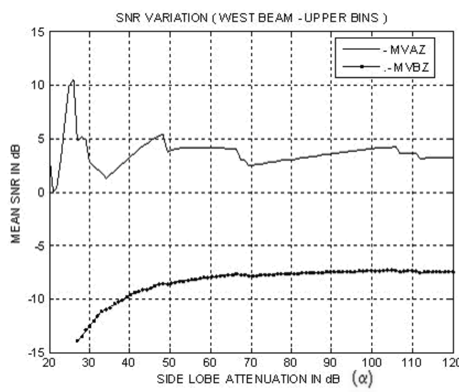

Figure.4(b)(iii): AVERAGE SNR Uppder Bins - West Beam

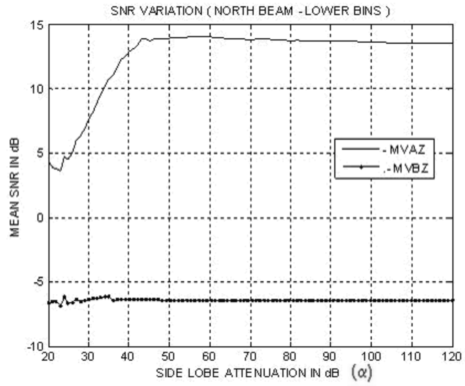

Figure.4(c)(i): AVERAGE SNR Lower Bins - North Beam

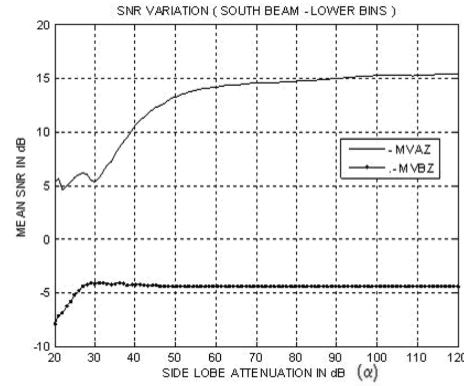

Figure.4(d)(i): AVERAGE SNR Lower Bins - South Beam

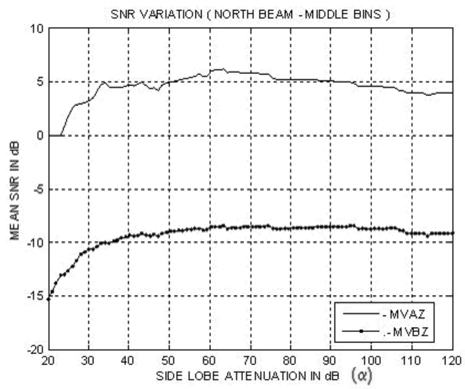

Figure.4(c)(ii): AVERAGE SNR Middle Bins - North Beam

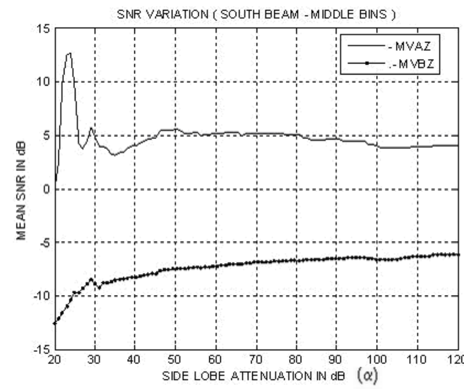

Figure.4(d)(ii): AVERAGE SNR Middle Bins – South Beam

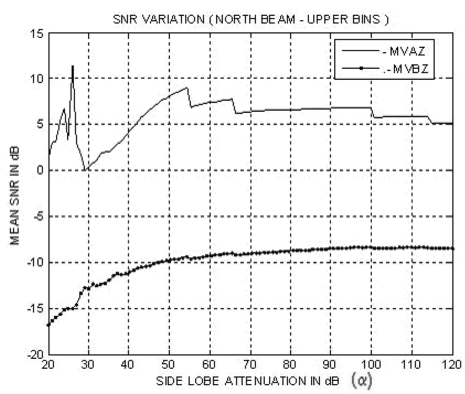

Figure.4(c)(iii): AVERAGE SNR Upper Bins - North Beam

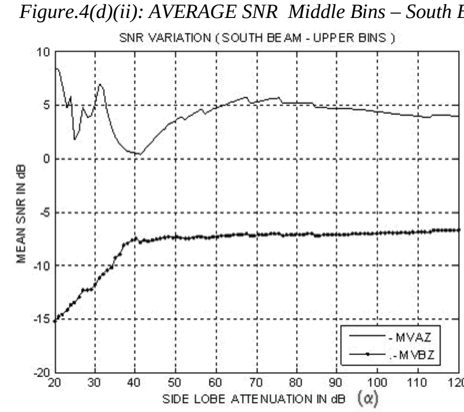

Figure.4(d)(iii): AVERAGE SNR Upper Bins - South Beam

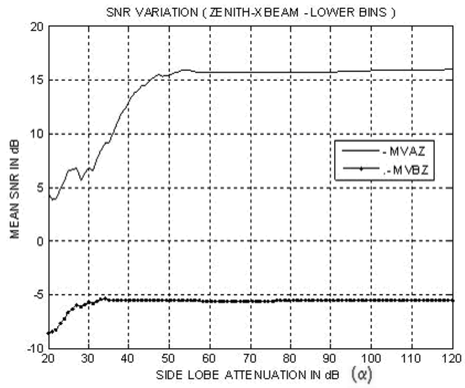

Figure.4(e)(i): AVERAGE SNR Lower Bins – Zenith-X Beam

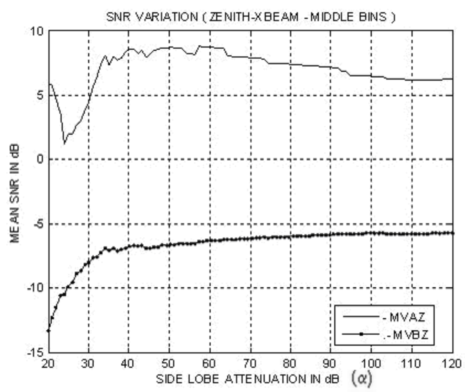

Figure.4(e)(ii): AVERAGE SNR Middle Bins – Zenith-X Beam

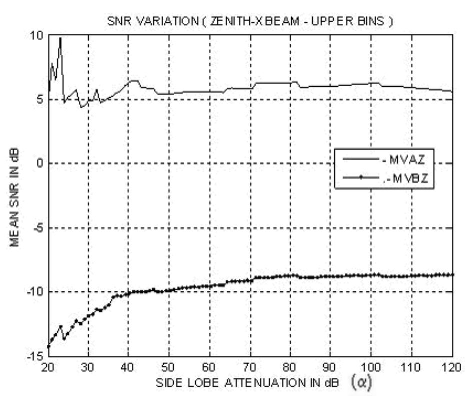

Figure.4(e)(iii): AVERAGE SNR Upper Bins – Zenith-X Beam

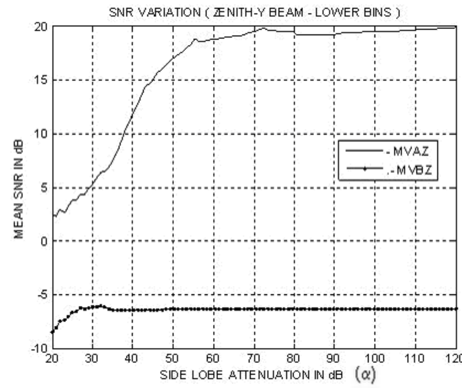

Figure.4(f)(i): AVERAGE SNR Lower Bins – Zenith-Y Beam

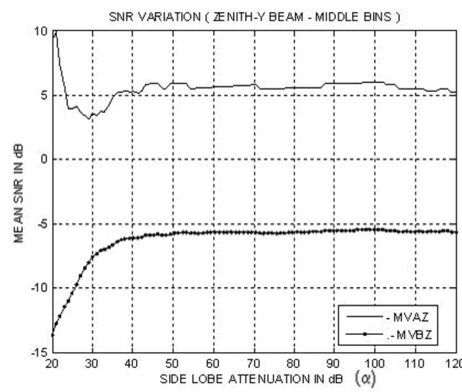

Figure.4(f)(ii): AVERAGE SNR Middle Bins – Zenith-Y Beam

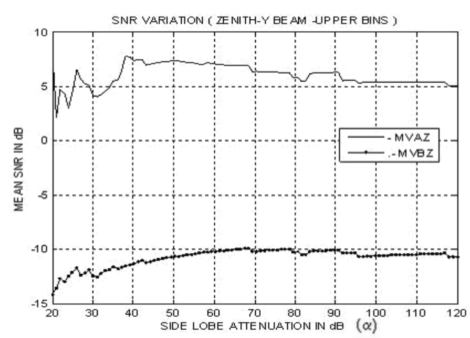

Figure.4(f)(iii): AVERAGE SNR Upper Bins – Zenith-Y Beam

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