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EFFECT OF WINDOWING ON SNR OF MST RADAR SIGNALS

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Abstract

In this paper, the effect of windowing the radar data on the SNR values of MST radar returns has been investigated. It is observed that the windows with good side lobe behavior improve the SNR values especially for the data from higher regions. This study also recommends the suitable windows to analyze the MST radar signals.

1. 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 [5, 8, 12] 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

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[7]. This paper presents a comparative study of various windows to improve the SNR of radar returns and suggests the suitable windows with which radar data may be weighed to compute spectral information.

2. The Data Weighting Windows

Windowing

Windows are time-domain weighting functions that are used to reduce Gibbs' oscillations resulting from the truncation of a Fourier series [18]. It is well known [5, 8, 12], 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 [8, 12]. 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 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 [5].

A good survey on windows is reported in the literature [4, 5, 8, 9, 10, 12-14, 17]. Windows can be categorized as fixed or adjustable [1, 4, 13]. 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 [5]. The Kaiser window [5, 9, 16] has two parameters and achieve close approximations to discrete prolate functions that have maximum energy concentration in the main lobe. The Dolph-

Chebyshev window [5, 11, 18] has two parameters and produces the minimum main-lobe width for a specified maximum side-lobe level. 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.

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* [5, 10].

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 [6] and a corresponding underestimate of signal-to-noise ratio.

3. Window Technique Applied to Atmospheric Radar Signals

Wind profile detection of a MST Radar signal meant the measurement of Dopplers 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 Radars are analyzed with power spectrum, which specifies the spectral characteristics of a signal in frequency domain.

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

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	2001-2003
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

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

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

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

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

Since the SNR is not constant but varies from bin to bin, the study of the window performance on the SNR values of the atmospheric signals, we have divided the 150 bin atmospheric data into three equal parts of each consisting of 50 bins, viz., LOWER BINS, MIDDLE BINS and UPPER BINS. In each of these three regions, the mean value of SNR is computed as the SNRs below zero dB and the SNRs above zero dB. We name them as MVBZ (Mean Value Below Zero) SNR and MVAZ (Mean Value Above Zero) SNR, respectively. The SNR computation [2, 3, 6] for the six sets of Radar data using various windows is carried on and presented in Tables 2(a)-(f). 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 8th July, 2002. 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 complete implementation of the scheme using C++ and Matlab, to study the effect of windowing on the SNR of the radar returns can be put as follows:

Algorithm

STEP 1. Select the window.

STEP 2. Taper the radar data with the selected window STEP 1.

STEP 3. Perform the Fourier analysis of the above tapered data [2, 3].

STEP 4. Compute the SNR using the procedure [2, 3, 6].

STEP 5. Compute the Mean Value Below Zero SNRs (MVBZ).

STEP 6. Compute the Mean Value Above Zero SNRs (MVAZ).

STEP 7. Go to the STEP 1 and repeat the entire sequence of steps above.

4. Results and Discussion

The SNR computation [2, 3, 6] for the six sets of Radar data is carried out and presented in Tables 2(a)-(f). From the Tables 2(a)-(f), it is observed that there is no appreciable change in MVAZ for all the six sets of data and the value represents positive SNR hence there is no much importance to this result. But the value of MVBZ plays crucial role, as it represents the noise level which is predominant over signal level. It is observed that, maximum value of the MVBZ is reported by BLACKMAN-HARRIS, BOHMAN and NUTTAL windows for the MIDDLE BINS. For the upper bins, the maximum MVBZ is observed, when the radar data is weighted by the BLACKMAN-HARRIS, BOHMAN, NUTTAL and PLATTOP windows. Further, it is observed that BLACKMAN window also performs well for the beams Zenith X and Zenith Y.

Using these windows, an improvement of 4dB to 7dB is observed when compared with RECTANGULAR window. This result is important, since the back-scattered signal from the middle and uppermost bins is very weak and improvement in SNR is highly desirable in spectral estimation.

Noting the above observations, it is concluded that BLACKMAN-HARRIS, BOHMAN, NUTTAL can be used in place of RECTANGULAR or HAMMING WINDOWS. The results also suggest that the effect of side lobe reduction in the improvement of SNR of noisy data, since the recommended windows exhibit very good side lobe behavior [5, 10] and therefore demands for the design of optimal windows.

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Table 2(a). AVERAGE SNR of LOWER, MIDDLE and UPPER Bins for "EAST" Data Collected from NARL, Gadanki, INDIA on 8th July, 2002

WINDOW	LOWER BINS		MIDDLE BINS		UPPER BINS	
	MVBZ (dB)	MVAZ (dB)	MVBZ (dB)	MVAZ (dB)	MVBZ (dB)	MVAZ (dB)
RECTANGULAR	–4.1324	10.4507	–11.3511	8.9080	–15.1178	8.9404
TRIANGULAR	–13.2996	11.2563	–9.2789	9.7945	–8.9606	9.5073
BLACKMAN	–7.5725	11.0164	–8.1743	8.3713	–7.2799	8.0379
HANN	–6.2426	11.1202	–8.6863	8.7580	–7.9508	8.6698
HAMMING	–6.8464	11.2465	–9.0973	8.9468	–8.7544	8.8192
KAISER $(\beta = 6)$	–7.5412	11.0095	–8.9205	8.7888	–8.3604	8.5713
BARTHAN	–7.1735	11.0929	–9.0141	8.8309	–7.9881	8.7300
BLACKMAN-HARRIS	–6.7389	11.1099	–7.5190	9.2653	–6.9223	9.0772
BOHMAN	–6.0942	10.9700	–8.0954	8.7867	–7.3008	8.4494
CHEBWIN $(\alpha = 3)$	–6.4444	11.0568	–8.8370	8.7596	–8.0878	8.4225
PLATTOP	–7.3888	10.1226	–7.2941	7.1076	–6.8482	7.7551
GAUSSWIN	–6.2578	10.6015	–8.7744	8.5752	–8.0585	8.3361
NUTTALWIN	–6.7976	10.5665	–7.5856	8.5013	–6.9599	8.3462
BARTLETT	–6.1474	10.7066	–8.8930	9.3711	–8.9398	9.1103

Table 2(b). AVERAGE SNR of LOWER, MIDDLE and UPPER Bins for "WEST" Data collected from NARL, Gadanki, INDIA on 8th July, 2002

WINDOW	LOWER BINS		MIDDLE BINS		UPPER BINS	
	MVBZ (dB)	MVAZ (dB)	MVBZ (dB)	MVAZ (dB)	MVBZ (dB)	MVAZ (dB)
RECTANGULAR	–2.6418	11.0235	–10.4418	9.7543	–14.5022	9.7876
TRIANGULAR	–13.3601	10.2675	–8.4312	9.2050	–9.3267	9.2286
BLACKMAN	–8.5532	10.5644	–6.7734	9.3241	–8.0202	8.8267
HANN	–7.4318	10.2446	–6.8051	9.6695	–8.1257	9.5015
HAMMING	–7.8138	10.1263	–6.9555	9.2618	–8.9374	9.1609
KAISER $(\beta = 6)$	–8.3607	10.3285	–6.6243	10.0620	–8.3371	9.8783
BARTHAN	–7.8270	10.2789	–6.9079	9.2815	–8.3919	9.1035
BLACKMAN-HARRIS	–8.1459	10.5125	–5.9560	9.6055	–7.5441	8.9191
BOHMAN	–6.7397	10.8343	–6.3630	9.6331	–7.7713	9.1504
CHEBWIN $(\alpha = 3)$	–7.2033	10.5052	–6.5347	10.2086	–8.1489	9.9829
PLATTOP	–7.8210	11.4815	–5.6345	9.6081	–7.3024	9.2894
GAUSSWIN	–6.6174	10.4691	–6.5208	10.1763	–8.5471	9.9797
NUTTALWIN	–8.2803	10.4934	–6.1127	9.3358	–7.5696	8.6403
BARTLETT	–7.1283	10.3009	–7.0844	9.2663	–9.3093	9.2907

Table 2(c). AVERAGE SNR of LOWER, MIDDLE and UPPER Bins for "NORTH" Data collected from NARL, Gadanki, INDIA on 8th July, 2002

WINDOW	LOWER BINS		MIDDLE BINS		UPPER BINS	
	MVBZ (dB)	MVAZ (dB)	MVBZ (dB)	MVAZ (dB)	MVBZ (dB)	MVAZ (dB)
RECTANGULAR	–5.7797	13.7880	–10.8925	12.7591	–14.7265	12.7470
TRIANGULAR	–14.4976	14.0716	–10.8238	11.4744	–10.3047	11.5201
BLACKMAN	–10.1198	13.8109	–8.6179	10.8286	–8.5949	10.7443
HANN	–8.4550	14.1696	–8.3465	11.4062	–9.1438	11.3929
HAMMING	–8.9678	14.0699	–8.5594	12.1232	–9.8049	12.1014
KAISER $(\beta = 6)$	–9.6181	14.0751	–8.9784	11.3661	–9.3686	11.2908
BARTHAN	–9.1957	14.0928	–8.4155	11.8362	–9.1878	11.8407
BLACKMAN-HARRIS	–9.0282	13.5993	–8.3321	9.8875	–8.1946	9.8361
BOHMAN	–8.0958	13.7982	–7.7985	10.8059	–8.4088	10.7279
CHEBWIN $(\alpha = 3)$	–8.2743	14.0172	–8.0817	11.9872	–9.1147	11.7355
PLATTOP	–8.8584	13.4835	–7.7956	11.2699	–8.1577	10.5000
GAUSSWIN	–8.1154	13.9121	–8.4136	11.7997	–9.3394	11.6730
NUTTALWIN	–9.1809	13.6263	–8.4291	10.1979	–8.2522	10.1356
BARTLETT	–8.1189	14.0699	–8.8920	11.4742	–10.2838	11.5210

Table 2(d). AVERAGE SNR of LOWER, MIDDLE and Upper Bins for "SOUTH" Data collected from NARL, Gadanki, INDIA on 8th July, 2002

WINDOW	LOWER BINS		MIDDLE BINS		UPPER BINS	
	MVBZ (dB)	MVAZ (dB)	MVBZ (dB)	MVAZ (dB)	MVBZ (dB)	MVAZ (dB)
RECTANGULAR	–3.3143	14.1649	–10.6580	12.7120	–12.7254	12.7578
TRIANGULAR	–12.6043	14.6810	–8.8662	12.4535	–8.3336	12.4309
BLACKMAN	–8.2954	14.7008	–6.8612	11.2441	–7.9166	10.9880
HANN	–7.9570	14.3736	–7.7806	11.3302	–7.9527	11.2618
HAMMING	–7.9602	14.3654	–7.8582	11.7976	–8.0448	11.8733
KAISER $(\beta = 6)$	–8.0223	14.3969	–7.3348	11.3057	–7.9074	11.3558
BARTHAN	–7.8967	14.4371	–7.5086	11.3149	–7.9556	11.3276
BLACKMAN-HARRIS	–7.9555	15.2577	–6.9616	10.0723	–7.7573	9.6607
BOHMAN	–7.8214	14.7796	–7.2757	10.5484	–7.7452	10.2976
CHEBWIN $(\alpha = 3)$	–7.8007	14.1879	–7.6125	10.8592	–7.9173	10.7917
PLATTOP	–7.9693	15.7768	–7.4174	10.2671	–6.9908	9.4290
GAUSSWIN	–7.0901	14.4791	–7.9202	11.0047	–8.2197	10.9283
NUTTALWIN	–8.2162	15.3098	–7.3663	9.3811	–7.7028	8.9978
BARTLETT	–7.7656	14.6798	–8.0227	12.4545	–8.3004	12.4368

Table 2(e). AVERAGE SNR of LOWER, MIDDLE and UPPER Bins for "ZENITH-X" Data collected from NARL, Gadanki, INDIA on 8th July, 2002

WINDOW	LOWER BINS		MIDDLE BINS		UPPER BINS	
	MVBZ (dB)	MVAZ (dB)	MVBZ (dB)	MVAZ (dB)	MVBZ (dB)	MVAZ (dB)
RECTANGULAR	–2.3384	15.2010	–10.0748	13.9788	–12.2853	13.2748
TRIANGULAR	–12.5144	15.8407	–8.3890	13.9558	–8.4796	13.4080
BLACKMAN	–8.7248	15.6818	–7.4133	12.5251	–7.3546	13.0383
HANN	–7.4960	15.8236	–7.0013	13.6128	–8.2722	13.2256
HAMMING	–8.3973	15.8974	–7.1769	13.8051	–8.5983	13.3219
KAISER $(\beta = 6)$	–8.7399	15.8717	–7.3046	13.9272	–8.4136	13.4694
BARTHAN	–8.5576	15.8930	–6.8821	13.9721	–8.4439	13.3496
BLACKMAN-HARRIS	–8.3458	15.9279	–7.3375	11.6385	–7.3574	12.1778
BOHMAN	–7.4986	15.7234	–6.6718	12.4437	–7.4791	12.7483
CHEBWIN $(\alpha = 3)$	–7.6315	15.6709	–7.0833	13.2610	–8.3214	13.0095
PLATTOP	–8.0488	16.6633	–6.9280	11.0765	–7.4905	11.0731
GAUSSWIN	–7.6392	15.8269	–7.2500	13.5412	–8.5392	13.1924
NUTTALWIN	–8.4367	15.9423	–7.4213	11.6819	–7.4133	12.2380
BARTLETT	–7.5701	15.8516	–6.9399	13.9649	–8.4641	13.4104

Table 2(f). AVERAGE SNR of LOWER, MIDDLE and UPPER Bins for "ZENITH-Y" Data collected from NARL, Gadanki, INDIA on 8th July, 2002

WINDOW	LOWER BINS		MIDDLE BINS		UPPER BINS	
	MVBZ (dB)	MVAZ (dB)	MVBZ (dB)	MVAZ (dB)	MVBZ (dB)	MVAZ (dB)
RECTANGULAR	–4.3507	16.7897	–8.0253	13.6297	–11.3877	14.5567
TRIANGULAR	–11.4179	19.7643	–7.2507	13.9325	–9.2346	14.2000
BLACKMAN	–9.2292	19.4395	–7.1632	14.1568	–7.9271	14.2904
HANN	–7.9971	19.1630	–6.7153	14.5031	–8.2989	14.6786
HAMMING	–8.3777	19.1670	–6.7088	14.5840	–8.9364	14.7744
KAISER $(\beta = 6)$	–8.9862	19.2671	–6.9423	14.4902	–8.3972	14.7297
BARTHAN	–8.4582	19.2150	–6.8904	14.4240	–8.5665	14.6922
BLACKMAN-HARRIS	–8.5665	19.5936	–7.0427	13.8836	–7.9952	13.7963
BOHMAN	–7.9952	19.1176	–6.8442	13.9359	–8.2275	13.7868
CHEBWIN $(\alpha = 3B)$	–8.1674	18.3719	–6.8601	13.8218	–8.1631	14.1168
PLATTOP	–8.1631	20.0987	–7.6758	11.3284	–7.7026	11.6600
GAUSSWIN	–7.7477	19.5681	–6.8723	14.7792	–8.4502	15.1076
NUTTALWIN	–8.4502	19.5214	–6.7777	14.1934	–8.0166	14.0414
BARTLETT	–7.9797	19.3826	–7.0552	13.7029	–9.2520	13.9669

■