Groud Clutter of Weather Radar Systems Based on IIR Elliptic Filter and MATLAB Software

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Abstract

Ground clutter is part of clutter radar echo signal which is useless, and impact accurate estimates of large data base. According to the time-domain characteristics of ground clutter, this paper research on IIR elliptic filter design methods and the impact of change filter parameters on ground clutter time-domain filter effect. In this paper, we use MATLAB software to design the IIR elliptic filter, and analysis the filter effect of the weather radar signals in the time-domain. From the simulation results we found that the 5th order elliptic IIR with width is 2m/s and the attenuation is 50dB had better balanced effects in the elimination of ground clutter.

Keywords

Ground clutter; Doppler weather radar; Time-domain filter; IIR elliptic filter; MATLAB software.

1. Introduction

Ground clutter is a significant issue for radar systems. Clutter is useless signal which is the part of the radar return. Clutter targets are very efficient reflectors of electromagnetic energy. Returns from ground-clutter targets, such as vegetation, ground terrain and man-made structures, routinely contaminate radar data and mask weather returns causing poor quality. The clutter contamination not only makes the base products unreliable, but also affects all downstream radar products [Subastian Torres, 2011].The strong clutter returns will cause significantly high reflectivity estimates. Clutter returns present in each range bin will bias the velocity estimate toward zero. Clutter contamination in the velocity estimate will affect the spectrum width estimate. A lot of research has been done on the mitigation of clutter and the issues it causes. The ideal system would remove all the energy from the return due to a clutter target, but leave the desired weather signal unaffected.

In this paper we research on time-domain of ground clutter and filter it with different parameter of IIR elliptic filter, in the experiment we found that the fifth-order elliptic IIR with width is 2m/s and the attenuation is 50dB had better balanced effects in the elimination of ground clutter.

2. The Basic Principle of Elliptic Filter to Remove Ground Clutter

Ground clutter filter is a high pass filter. Ideally, it can remove the both side of the zero frequency components of the frequency components in the Doppler frequency and leaving the others intact. For clutter filter designs, it is important to recognize that, because any change in the frequency response will make the strength, the Doppler frequency and the frequency spectrum width generate deviations [Liu Taorong et al., 2013]. Assuming the zero-order self-correlation of filtered weather echo signal is $R(0)$, first order self-correlation is $R(T)$ where T is the pules repetition period. Using PPP (pulse pair processing) method to estimate the spectral parameters (strength, average Doppler frequency and frequency spectral width) as follows:

Strength:

$$R = R(0) \tag{1}$$

Average doppler frequency:

$$\overline{f_d} = \frac{1}{2\pi T}\arctan\frac{I_m[R(T)]}{R_e[R(T)]} \tag{2}$$

Frequency spectral width:

$$\sigma_{fd} = \frac{\sqrt{2}}{2\pi T}\sqrt{1-\frac{|R(T)|}{R(0)}} \tag{3}$$

From the above expression we found these three parameters only depend on the estimate self-correlation function of the weather echo filtered signal. The output PSD (power spectral density) of linear time-invariant filter $S_y(\omega)$ is related with the frequency response magnitude squared of the filter $|H(\omega)|^2$ and the input power spectral desity $S_x(\omega)$.

$$S_y(\omega) = S_x(\omega)|H(\omega)|^2 \tag{4}$$

According to Parseval theorem, we can see the filtered self-correlation function of the weather echo signals corresponding to the PSD is a Fourier transform pair. Since the phase response of the filter is not included in this transformation, it does not have any effect on the associated filter output signal weather [Cao Longbin et al., 2008].

2.1 Realization of Elliptic filter

Elliptic filter pass band and stop band is adopt equal ripple approximate way, that is the best way of approaching which the filter order N has given. For the same performance requirements， it require lower order number than Butterworth filter and Chebyshev filter ,and its transition zone is relatively narrow. The steps of elliptical digital filter design as follow:

1).Identifying digital filter performance indicators: W_p, W_s, R_p, R_s;

2).Converting the analog filter performance indicators from digital filter performance indicators;

3).Design the analog filter which satisfies the required performance indicator $H_\alpha(s)$;

4).Convert the analog filter into a digital filter.

2.2 Analysis of Elliptic filter frequency response characteristic

Elliptic filter amplitude response in the pass band and the stop band are equally ripple, for a given order and given the requirements of corrugations, elliptical filter can be obtained over a narrow bandwidth compared to other filters. At this point, elliptical filter is optimal, the amplitude squared function is:

$$|H_\alpha(j\Omega)|^2 = \frac{1}{1+\varepsilon^2 R_N^2\left(\frac{\Omega}{\Omega_p}\right)} \tag{5}$$

Which $R_N(x)$ is the Jacobi elliptic function, is the relevant parameters of the attenuation in the pass band. The rational function $R_N(\omega)$ is:

When n is an odd number, k= (n-1)/2:

$$R_n(\omega) = \frac{\omega(\omega_1^2-\omega^2)(\omega_2^2-\omega^2)\cdots(\omega_k^2-\omega^2)}{(1-\omega_1^2\omega^2)(1-\omega_2^2\omega^2)\cdots(1-\omega_k^2\omega^2)} \tag{6}$$

When n is an even number, k=n/2:

$$R_n(\omega) = \frac{(\omega_1^2-\omega^2)(\omega_2^2-\omega^2)\cdots(\omega_k^2-\omega^2)}{(1-\omega_1^2\omega^2)(1-\omega_2^2\omega^2)\cdots(1-\omega_k^2\omega^2)} \tag{7}$$

3. R Elliptic Filter Parameters Affecting Ground Clutter Filtering

In the experiment, we process and analyze the weather radar signal, by adjusting the parameters of IIR elliptic filters to analyze the impact on the ground clutter time-domain signal. Which stop band bandwidth and attenuation these two parameters can be used to adjust and compare filters Filter can produce a number of products, including PPI plot of reflectivity, Doppler velocity, frequency bandwidth and spectral Doppler spectrum in detail. In order to decrease the impact of the width of the filter, we set to 50dB and the width 1m/s was changed to a width of from 1m/s to 3m/s. For comparison the depth of filter, the width of the filter is limited to 1m/s, and the minimum attenuation from 30dB to 60dB in increments.

3.1 The result of IIR Elliptic filter with different width to process the data

The following are radar data power PPI plot of different widths of the IIR filter after filtering:

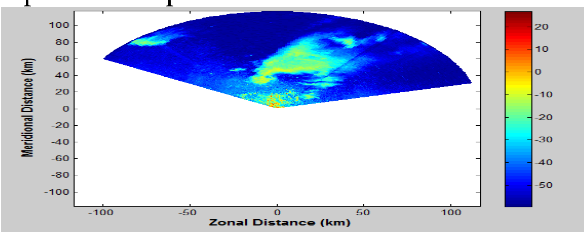

Figure 1. Power PPI plot of original radar data.

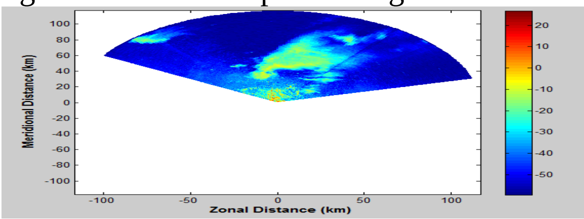

Figure 2. Width of 1m/s filter filtered power PPI plot.

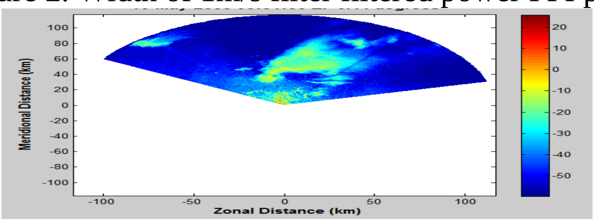

Figure 3. Width of 2m/s filter filtered power PPI plot.

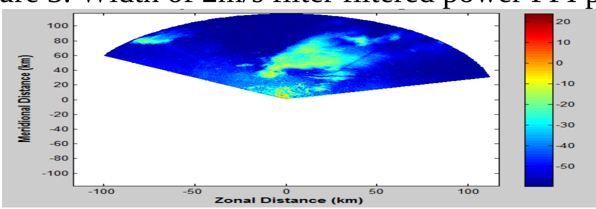

Figure 4. Width of 3m/s filter filtered power PPI plot.

From figure1 to figure 4 are the results of weather radar data which filtered by different width filter, the filtering effect of the filter with different widths are different. Compared with the original power PPI plot, the clutter near the zero Doppler frequency is significantly reduced after filter filters. That because the clutter is mainly near zero Doppler velocity.

The following figures are the velocity which the radar data filtered by different width filters:

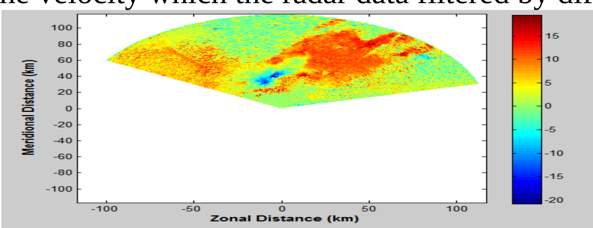

Figure 5. Velocity of original radar data.

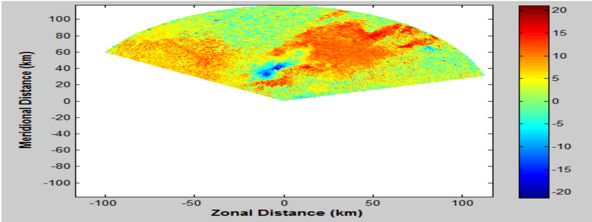

Figure 6. Width of 1m/s filter filtered velcocity PPI Figure .

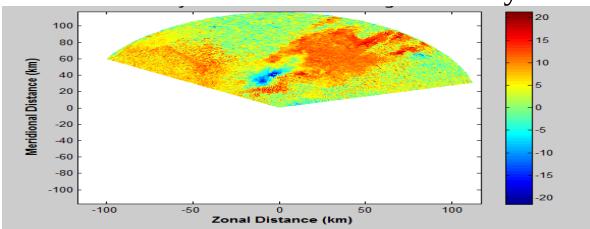

Figure 7. Width of 2m/s filter filtered velcocity PPI Figure.

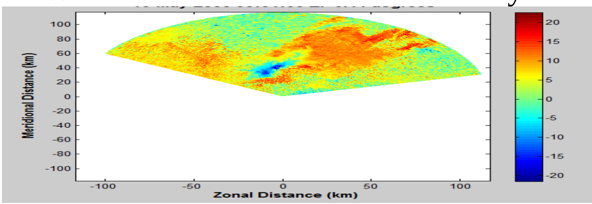

Figure 8. Width of 3m/s filter filtered velcocity PPI Figure.

From figure 5 to figure 8 are the velocity of weather radar data which filtered by different width filter. It is evident that after filtering, the useful wave which slightly higher than zero velocity is increased and Doppler speed about zero clutter is reduced. From the filter effect we found width with 2m/s filter effect was most obvious.

The following figures are spectrum width which the radar data filtered by different width filters.

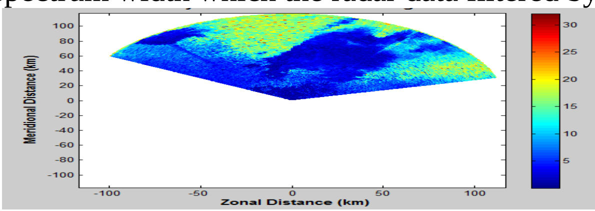

Figure 9. Spectrum width of original radar data.

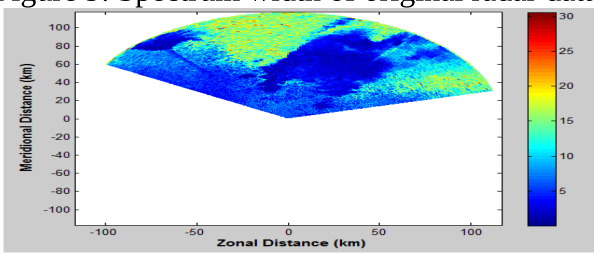

Figure 10. Width of 1m/s filter filtered spectrum width

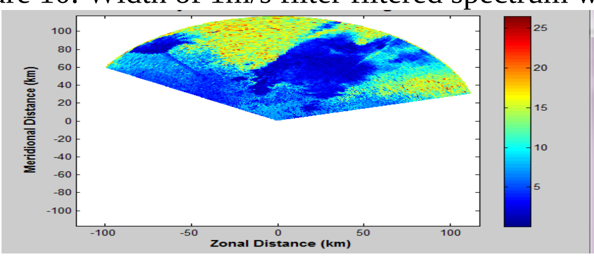

Figure 11. Width of 2m/s filter filtered spectrum width

From figure 9 to figure 12 are the spectrum width of weather radar data which filtered by different width filter. Compare the spectrum width of original radar date, the filter radar spectrum width changes wider. This is due to the width of the filter impact the Doppler spectrum of a signal. With the increase of the width of the filter, the maximum attenuation is closer to zero velocity and side lobes further away from the zero velocity.

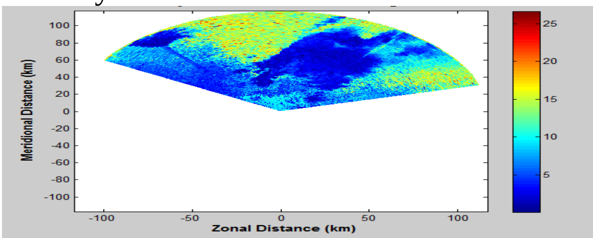

Figure 12. Width of 3m/s filter filtered spectrum width

3.2 The result of IIR Elliptic filter with different depth to process the data

The following are radar data power PPI plot of different attenuation of the IIR filter after filtering:

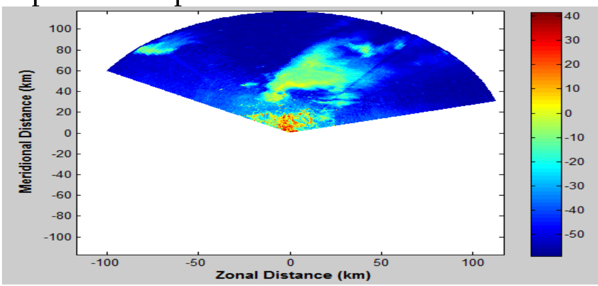

Figure 13. Power PPI plot of original radar data

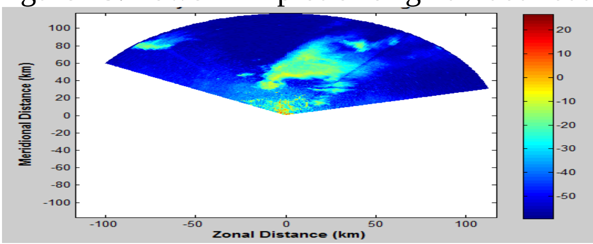

Figure 14. 30dB attenuation filter filtered power PPI plot

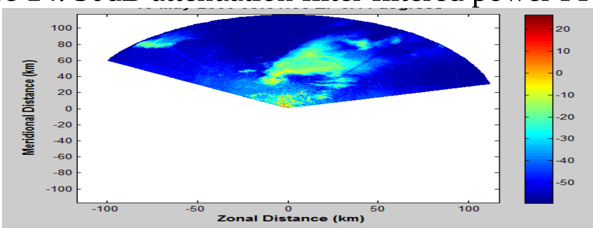

Figure 15. 40dB attenuation filter filtered power PPI plot

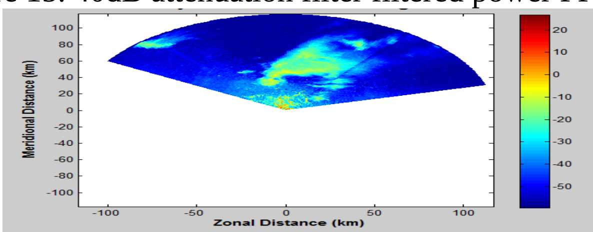

Figure 16. 50dB attenuation filter filtered power PPI plot

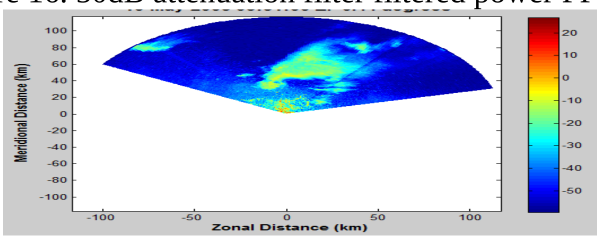

Figure 17. 60dB attenuation filter filtered power PPI plot

From figure 13 to figure 17 are original radar data power PPI plot and the power PPI plot of weather radar data which filtered by different depth filter. Compare the results, the power PPI plot have change obviously, clutter which concentrated in the vicinity of the zero Doppler velocity is reduced, that is red and yellow portion in the central area reduced.

The following figures are the velocity which the radar data filtered by different depth filters.

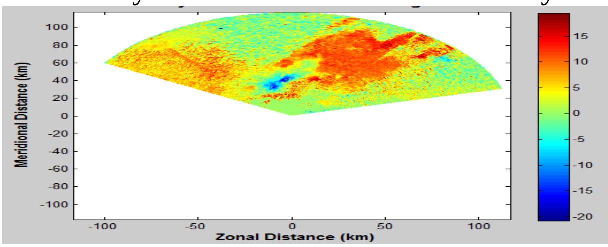

Figure 18. Velocity of original radar data

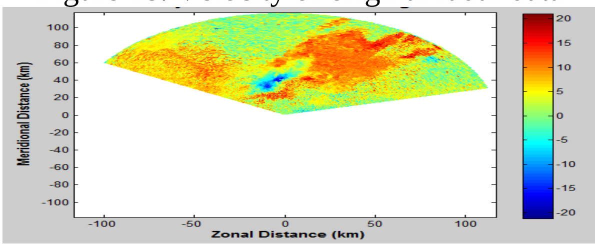

Figure 19. 30dB attenuation filter filtered velocity

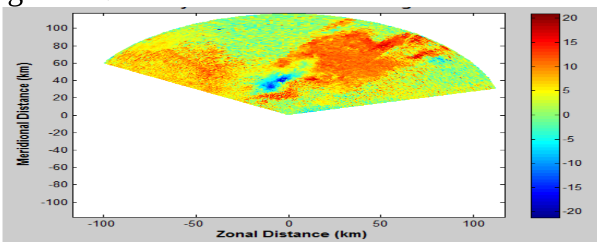

Figure 20. 40dB attenuation filter filtered velocity

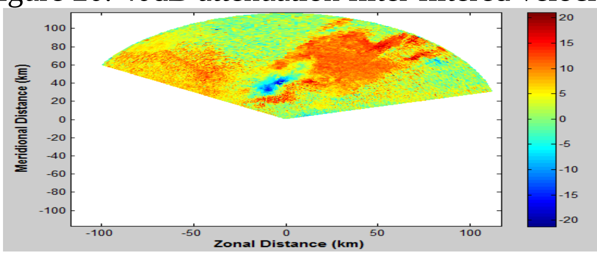

Figure 21. 50dB attenuation filter filtered velocity

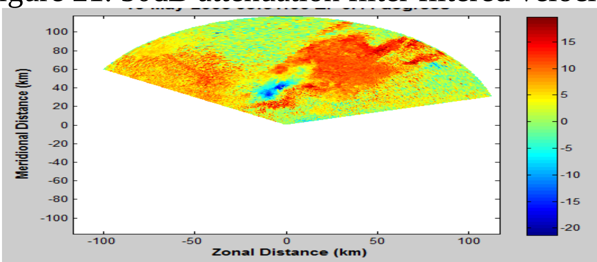

Figure 22. 60dB attenuation filter filtered velocity

From figure 18 to figure 22 are original radar data velocity and the velocity of weather radar data which filtered by different depth filter. From the result we found the velocity radar data change differently, comparing to the original radar date the clutter which close to zero clutter Doppler are reduced.

The following figures are the spectrum width which the radar data filtered by different depth filters.

From figure 23 to figure 27 are original radar data spectrum width and the spectrum width of weather radar data which filtered by different depth filter. From the result we found the spectrum width of the radar data significantly wider, played a filter effect of clutter.

Compare three aspects: the power, velocity, spectrum width and the results from figure 13 to figure 27, the attenuation of 50dB filter filtering effect is ideal.

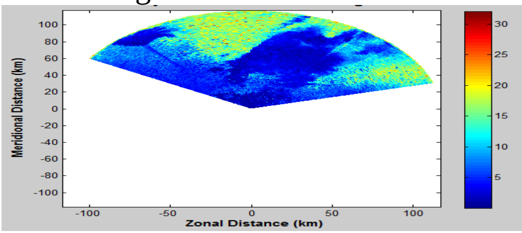

Figure 23. Spectrum width of original radar data

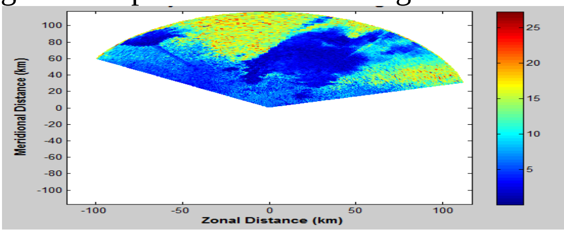

Figure 24. 30dB attenuation filter filtered spectrum width

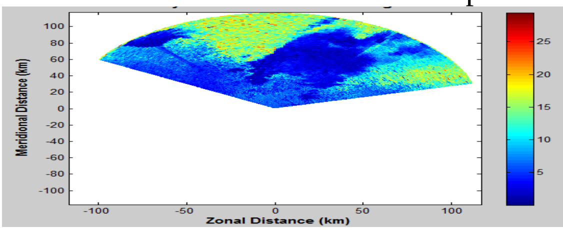

Figure 25. 40dB attenuation filter filtered spectrum width

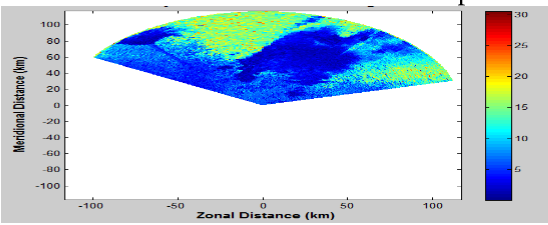

Figure 26. 50dB attenuation filter filtered spectrum width

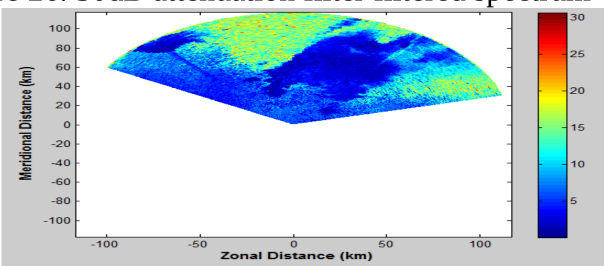

Figure 27. 60dB attenuation filter filtered spectrum width

3.3 The result of IIR Elliptic filter with different depth to process the data

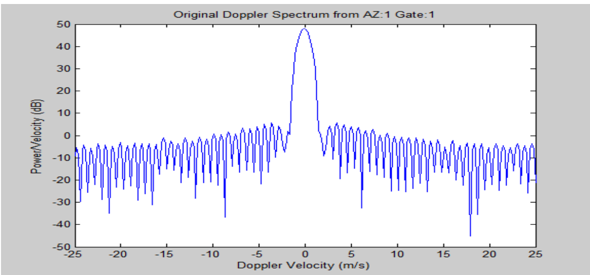

Figure 28. Original doppler spectrum

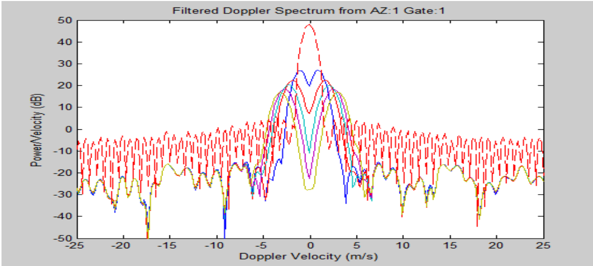

Figure 29. Order is 3,4,5,6,7,8 radar data filtering Doppler filter

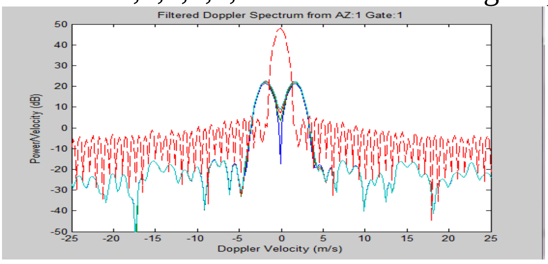

Figure 30. Filtered Doppler singnal by varying Filter Depth

From the figure we can see the details of each filter by Doppler effect on how the clutter signal, where the red line represents the original Doppler spectrum.

Figure 28 shows the width of the filter impact on the Doppler spectrum signals. With the increase of the width of the filter, the maximum attenuation is closer to zero velocity and zero velocity further away from the side lobes. Figure 29 shows that the attenuation at different depths have no much affect on Doppler spectrum signals. More likely to be attenuated in the vicinity of zero velocity signal, but with the increase in the minimum attenuation, the sidelobes become stronger. Therefore, in the filter attenuation depth reflection force and not affect very much.

In summary, the filter with attenuation of 50dB and a width of 2m /s have a good balance to filter the clutter, and the 5th order elliptic filter is performed well.

4. Conclusion

In this paper we use MATLAB software to design filters and focus on ground clutter time-domain filtering algorithm research. Clutter generally have a fixed source, and its velocity concentrated around zero Doppler frequency, ground clutter signal bandwidth is very narrow, and the Doppler velocity is zero, if the spectral components concentrated in the zero Doppler frequency, very a large portion of the interference signal will be weakened, we can solve this problem by selecting the appropriate filter. This filter can not only reduce the impact of clutter on the signal, but also can reduce the impact from the weather signal. From the filtering results, it appears that a 2m/s wide filter with a minimum attenuation of 50 dB is a good balance between removing the clutter, and minimizing the affect on the weather spectrum. A 5th order elliptical filter is very to implement on a signal processor in real time for filtering the ground clutter.

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