AMTI filter design for radar with variable pulse repetition period

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Abstract - This paper presents a design of a Doppler AMTI filter, for a radar with a variable pulse repetition period (stagger). The filter can suppress ground and volume clutter echoes simultaneously. The maximum filter impulse response length is limited to 5 coefficients due to a limited radar system stability and a radar antenna movement.

Keywords - Filter, frequency response, AMTI, FIR, MTI, impulse response, clutter, Doppler processing

1. INTRODUCTION

This work deals with a simple ground and volume clutter cancelation in monostatic radar with a variable pulse repetition period (stagger). The impulse response length is limited to a maximum of 5 coefficients according to the client’s requirements. This short filter is particularly suitable for semi-coherent (magnetron) radars with a low frequency stability, or where the antenna beam intercepts only a few impulse echoes. The processed data is in the form of a signal complex envelope. The data was provided by the company RETIA Inc.

The clutter consists of both the received echoes scattered from a static ground objects with zero Doppler frequency and the volume clutter of echoes scattered from moving meteor objects with nonzero Doppler frequency (figure 1). To detect and track airplanes or helicopters both clutter types should be extracted from the received signal. In history this problem has been solved using analog filters with two stop bands. Nowadays thanks to a high processors computation performance available, it is possible to solve this problem using digital Doppler filters.

2. CLUTTER PARAMETERS

In the figure 1 a transmitted pulse is scattered back by three typical objects: by a moving airplane, a moving meteor-clutter and a static ground clutter. The frequencies of the echoes are shifted by Doppler frequencies \( \omega_d \) \([1, 5, 7]\), which in the discrete time domain correspond to \( \Omega_d \):

\[
\omega_d = -4\pi \frac{v_d}{\lambda}; \quad \Omega_d = T_{op}\omega_d,
\]

where is \( v_d \) is the radial component of the scattering object velocity, \( T_{op} \) is a pulse repetition period and \( \lambda \) is the transmitted signal wavelength.

![Figure 1 – Transmitted and received signal](image1)

The discrete time complex envelope spectrum of the echo from static and moving objects is shown in the figure 2. It is evident that to suppress both clutter types we need two stopbands: one at the zero frequency and the other at the meteor-clutter Doppler frequency \( \Omega_d \).

![Figure 2 – The complex envelope spectrum of the received signal](image2)

The power and the Doppler frequency of a real signal are shown in the figures 3 and 4 where it is possible to note highly correlated echoes from a ground clutter and meteor-clutter. The depicted signal was received during one antenna revolution. The presented data were provided by the company RETIA Inc.
\[ x_1 = \cos \left( \frac{\Omega d}{2} \right) \]
1.1.1 Real AMTI filter with the “distant roots”

In the case of “distant roots” we require: \( |x_2| > 1 \). The calculation sequence should be as follows:

- Calculation of the discrete time Doppler angular frequency \( \Omega_d = 2\pi F_d \) and the first root \( x_1 = \cos(\Omega_d/2) \), where \( F_d = \omega_d T_{op} \)
- Selection of an auxiliary variable \( x_3 \in (-1,1); x_3 \neq 0 \).
- The second root calculation: \( x_2 = 1/x_3 \); (then \( |x_2| > 1 \)).

The examples of the AMTI filter characteristics with distant roots with different position of the second root \( x_2 \) are shown in the figure 6. It is obvious that an inappropriate choice of the second root position could create warped characteristics in the internal passband (i.e. in the band between the notches in the figure 6). To overcome this problem additional optimization conditions should be used. The first one is not to allow the transfer function to drop in this band. The convenient indicator of this condition could be the first derivative sign. If this sign changes more than twice in the internal passband it is evident that the characteristics is bent. The second condition requires balanced parameters outside the stop band as described in the equation (1.13).

\[
|H(\Omega = 0)| = |H(\Omega = \pi)| \tag{1.13}
\]
1.1.2 Real AMTI filter with “close roots”

In this case we are looking for two near solutions of the equation $H(\Omega) = 0$ in the range of $\Omega \in <0,\pi>$. Then: $|x_2-x_1| \equiv \Delta x << 1$. The calculations sequence should be as follows:

- Calculation of the discrete time angular Doppler frequency $\Omega_d = 2\pi F_d$ and $x_{10}$, the mean value of the $x_1$ and $x_2$: 
  $$x_{10} = \cos(\Omega_d/2) = 0,5.(x_1 + x_2),$$

- Selection of a positive value $\Delta x << 1$ (the roots $x_1$ and $x_2$ distance).

- Calculation of the roots:
  $$x_1 = x_{10} - \frac{\Delta x}{2}, x_2 = x_{10} + \frac{\Delta x}{2}.$$ 

The example of the power transfer function of a real AMTI filter with two close roots is displayed in the figure 8. This filter advantage is in the possibility to adapt the stopband width to the clutter spectra requirements changing the roots distance.

$$T_{\text{variable}} = T_{\text{op}} \pm dT$$ where $dT$ is a random variable in the range of $<-0,01T_{\text{op}}; 0,01T_{\text{op}}>$ with a uniform distribution (the staggered signal). The both signals undergo the AMTI filtration and filter transfers for a staggered and non-staggered signals are computed.

Figure 9 compares frequency responses of the AMTI filter with distant roots for the staggered and for the constant sample period signal. It is evident that in the stopband the staggered period signal characteristics is much worse than that of the constant period one. The figure 10 displays the same situation for an AMTI filter with “close roots”. We can see, that in this case the suppression deterioration due to the stagger is less significant.

![Figure 9](image9.png)  
**Figure 9** - Frequency response of an AMTI filter with “distant roots” for a staggered and non-staggered period signal

![Figure 10](image10.png)  
**Figure 10** - Frequency response of an AMTI filter with “close roots” for a staggered and non-staggered period signal

4. CASCaded AMTI FILTER

This structure consists of two cascaded MTI filters (figure 11). Each MTI filter has one stop band at zero Doppler frequency for clutter suppression. After ground clutter suppression in the first filter the signal frequency is shifted by the Doppler frequency $\Omega_d$ of the moving meteor-clutter so that its power spectrum will appear at zero frequency again. And then it is suppressed using the second MTI filter [1].
This MTI filter pulse response is described by the following equation (1.14) [4, 5, 6].

\[ h_{MTI}(t) = \delta(t) - 2\delta(t - T_{op}) + \delta(t - 2T_{op}), \]

where \( T_{op} \) is the (constant) radar repetition period.

The figure 12 A) displays the spectrum of the input signal at the first MTI filter and in the figure 12 B) the spectrum of \( s_2(t) \) after frequency shifting is shown. The frequency shift is described using the following equation (1.15):

\[ |S_2(\Omega)| = |S_{in}(\Omega - \Omega_d)| \to s_2(t) = e^{-j\Omega_d t}S_{in}(t), \]

where \( S_{in} \) is spectrum of the signal complex envelope at the mixer input and \( S_2 \) is the spectrum at its output shifted by the Doppler frequency \( \Omega_d \).

5. AMTI FILTER REAL DATA TESTING

The figure 14 illustrates a power and a Doppler frequency of a real received signal during one radar antenna revolution at a particular distance before and after filtration by the both versions of the real AMTI filter. The area with meteo-clutter we can find from the Doppler frequency plot as the wide area of nonzero Doppler shifts. In the power plots the blue and red curves represent the signal before and after filtration respectively. From here we can see that the both filters can suppress the both clutter types below the noise level. The input signal includes also a reflection of a moving aircraft. Its signal to noise ratio is principally not affected by the filtration, being about 20 dB at the filters output.
6. CONCLUSION

In this paper the design of the AMTI filter was described. Two new algorithms for coefficients computation for a real AMTI filter were introduced. The main advantage of the design with the “close roots” is a direct design of a filter with wide filter stopbands. The design with the “distant roots” needs a numerical optimization (par. 1.1.1) and leads to narrower stopbands. Finally, the cascaded AMTI filter was discussed. It was shown that it has not as good characteristics as the previous one. In the last chapter the both designs of the real AMTI filter were tested with real measured data. It was verified that the both suggested filter designs work satisfactorily.

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REFERENCES


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