International Journal of
Science, Architecture, Technology and Environment

Evaluation of Blind-Speed Mitigation and Moving Target Filtering in Surface-to-Air Missile Control Radars

Le Dinh Tuyen[1*]

[1]*Air Defence - Air Force Academy, Ha Noi, Viet Nam*

**Corresponding author: tuyenchien89@gmail.com*
DOI: https://doi.org/10.63680/ijsate1125012.008

Abstract

This study aims to develop an intuitive and user-friendly simulation interface that supports the evaluation of blind-speed mitigation techniques in pulse-Doppler radar systems. By enabling users to conveniently adjust key input parameters—specifically the pulse repetition period and transmitted frequency—the interface facilitates the visualization and assessment of corresponding output characteristics. Using MATLAB, the amplitude–velocity characteristic (ACX) curves of the Moving Target Detection (MTD) filter bank are analyzed across operational modes of a surface-to-air missile (SAM) control radar. Through the examination of blind-speed suppression by varying the pulse repetition period, the proposed tool allows users to effectively evaluate the improvement in blind-speed coverage and understand the influence of pulse-repetition-period modifications on the occurrence of blind speeds. The results demonstrate the usefulness of the developed interface in supporting radar-system analysis, educational training, and engineering design related to MTD processing.

Keywords: amplitude–velocity characteristic (ACX), Moving Target Detection (MTD, modes of a SAM.

1. Introduction

Pulse-Doppler radar systems play a critical role in modern surface-to-air missile control stations, where reliable detection of moving targets is essential for guidance and engagement accuracy. A fundamental challenge in such systems is the occurrence of blind speeds, which arise when the Doppler frequency of a moving target coincides with the nulls of the radar's filter response, causing the target echo to be significantly attenuated or lost within clutter [1], [2]. Traditional Moving Target Detection (MTD) processing employs a bank of Doppler filters designed to separate target signals from ground clutter and interference; however, its effectiveness depends heavily on radar parameters such as the pulse repetition period (PRP) **and the** transmitted carrier frequency **[3].**

To mitigate blind-speed effects, adaptive adjustment of PRP or transmitted frequency has been widely studied as an effective approach to redistribute Doppler nulls and improve detection probability [4], [5]. Although these principles are well established in radar theory, practical experimentation with PRP and frequency variations remains challenging for students and system designers due to the mathematical complexity and limited accessibility of operational radar equipment.

To address these limitations, this study develops a user-friendly simulation interface that enables interactive exploration of blind-speed mitigation techniques. The interface allows users to modify key radar parameters—specifically the pulse repetition period and transmitted frequency—and immediately observe their impact on the amplitude–velocity characteristic (ACX) curves generated by the MTD filter bank. MATLAB is employed as the computational environment to calculate and visualize ACX characteristics under various radar operating modes [6].

By analyzing the relationship between PRP adjustments and blind-speed suppression, the simulation environment helps users understand how parameter modifications shift Doppler filter nulls and enhance target detectability. The tool not only supports academic training in radar-signal processing but also provides a practical platform for evaluating design options in missile-control radar systems. Through this approach, the study contributes an accessible method for examining blind-speed mitigation strategies and deepening understanding of MTD performance in real-world scenarios [7].

2. Building a mobile target filtering algorithm using anti-blindness method

The amplitude-speed characteristic (ACX) of the anti-interference system is the dependence of the amplitude of the visual signal on the output of the device minus the radial velocity of the objects or on the Doppler frequency corresponding to the velocity.

For the 1-subtract ЧПВ device (under the condition of the transmission coefficient of the straight channel and the slow channel being the same), the dependence of the amplitude of the target signal on the output of the ЧПВ on the radial velocity is determined by the expression:

$$U_{ВЫХ}(V_r) = U_М \cdot \sin\pi \cdot F_{Д0} \cdot T_П = U_М \cdot \sin\frac{2\pi \cdot V_r \cdot T_П}{\lambda_0} \quad (1)$$

From this it follows that the maximum amplitude of the output pulses varies sinusoidally from 0 (at the "blind" speed when $F_{Д0} = k \cdot F_П$) to the value UM (at the optimal speed when $F_{Д0} = (2k-1)\cdot\frac{F_П}{2}$, k = 1, 2, 3 ...).

The graphs often give the normalized characteristic corresponding to the expression:

$$A = \frac{|U_{ВЫХ}(V_r)|}{U_М} = \left|\sin\pi \cdot \frac{2\cdot V_r}{\lambda_0} \cdot T_П\right| = \left|\sin\pi \cdot F_{Д0} \cdot T_П\right| \quad (2)$$

In practice, the target signals may be in a synthetic background consisting of both artificial and natural negative interference, and it is impossible to compensate them simultaneously with only one negative interference device. Therefore, in the missile control station there is a compensator consisting of 2 levels of interference suppression. Each level ensures ЧПВ 2 times. Each level of interference suppression can be adjusted by the operator for negative interference on the frequency FП1 or FП2. The quality of the interference compensation is checked on the displays of the station.

2.3. Method to prevent "blind" speed

When talking about "blind" speed, we think of the fixed value of the target radial velocity at which the amplitude-speed characteristic curve is deeply concave to the value 0:

$$V_{rЦ\ СЛЕП} = k \cdot \frac{\lambda_0}{2T_П}, \text{ where k= 1, 2, 3} \quad (3)$$

In fact, when subtracting many times, there will exist a "blind" speed region defined as the following speed segment:

$$V_{rЦ\ СЛЕП} = k \cdot \frac{\lambda_0}{2T_П} \pm \Delta V_r \text{ (or) } F_{Д0} = k \cdot F_П \pm \Delta F_Д \quad (4)$$

Because the target signal can only be observed when its amplitude exceeds the noise level as well as the residual signal level of the interference. The range is the segment where the target signal amplitude output of the subtractor is smaller than the noise level and the residual signal level of the interference, so we must apply some measure to prevent "blind" speed.

From comparing the amplitude-speed characteristics, we see that increasing the number of subtraction stages increases the suppression of noise fluctuations, but expands the "blind" speed region. From the expression it follows that the elimination of the "blind" rate can be achieved by changing the carrier frequency of the station (2) or by changing the repetition period of the probe pulse (1). Changing the carrier frequency of the station has technical difficulties, therefore, to eliminate the "blind" rate of the target, it is necessary to gradually change the repetition period when the target signal begins to disappear or continuously alternate repetition periods of different lengths. The first method has the advantage of very high filtering quality, but the disadvantage is that it changes the operating modes of many devices in the station. Therefore, in the pulse-correlated radar station (including the missile station), continuous interleaving of repetition periods of different lengths is used and synchronously changing the parameters of the delay channels of the device through the cycle. These cycles are chosen to satisfy the condition . The change of the repetition period must be carried out so that the Doppler drift of the signal over successive repetition periods differs by an amount close to the value of π, that is:

$$\Delta\phi_{T2} - \Delta\phi_{T1} = \frac{2 \cdot V_{rЦ}}{c} \cdot (T_{П2} - T_{П1}) \cdot \omega_0 \approx \pi \tag{5}$$

Then, if for this repetition period the velocity of the target is "blind velocity", then for the other repetition period the same velocity will be close to the "optimum velocity".

From the above expression we see that the value of the necessary change of the repetition period depends on the velocity value of the moving target:

$$\Delta T = \left(T_{П2} - T_{П1}\right) = \frac{\pi \cdot c}{2 \cdot V_{rЦ} \cdot \omega_0} = \frac{\pi \cdot c}{4 \cdot V_{rЦ} \cdot \pi \cdot f_0} = \frac{\lambda_0}{4 \cdot V_{rЦ}} \tag{6}$$

For fast-flying targets the relative change of the repetition period is small, while for slow-flying targets the relative change of the repetition period is large.

The АСХ characteristic of the СДЦ system for the alternating repetition period of the radar station can be approximated as the arithmetic mean value of АСХ at fixed repetition periods and . For 1-time ЧПВ it looks like Figure 1.

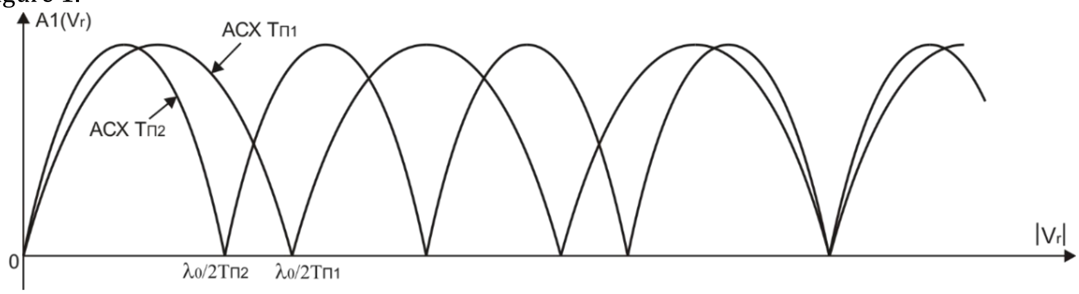

Figure 1 АСХ for the repeating cycle and alternating

It should be noted that the periodicity of АСХ when alternating the repeating cycle will be equal to . Thus, when the repeating cycle is alternating in the radial velocity range of the target 0 < Vr < then the amplitude of the target signal on the output of the subtractor is never 0, that is, the "blind" speed effect is eliminated or more precisely the "blind" speed region is shifted to the larger speed region. Then the smaller the value, the further the first "blind" speed is pushed into the large Vr region. However, then the depth of the sink zone at the beginning and end of the working part of АСХ increases, which limits the range reduction limit.

To overcome the "blind" speed zone in the large speed range, in the missile control station, two repetition cycles are used in two modes:

- Slow target mode - МССЦ
- Fast target mode - БСЦ

In the slow target mode (МССЦ), the repetition cycle of the station is ТП1 = 252 µs, ТП2 = 308 µs and corresponds to the speed range Vr = (70 - 220) m/s. In the fast flight mode (БСЦ) ТП1 = 272 µs, ТП2 = 288 µs and corresponds to the speed range Vr = (180 - 650) m/s.

For the control station of the surface-to-air missile, 3 repetition cycles are used in four modes:

- МД + БП: ТП1 = 261 µs, ТП2 = 279 µs, ТП3 = 297 µs.
- МД + БП: ТП1 = 354 µs, ТП2 = 372 µs, ТП3 = 390 µs.
- БД + БП: ТП1 = 528 µs, ТП2 = 558 µs, ТП3 = 588 µs.
- БД + БП: ТП1 = 631 µs, ТП2 = 651 µs, ТП3 = 681 µs.

Then the effect of "blind" speed will be eliminated in the entire range of the actual speed of the target.

In addition, to eliminate the influence of "blind" speed, we can use the simultaneous operation of several carrier frequencies or several reference frequencies. These frequencies are chosen so that the "blind" speed corresponding to the above frequencies does not coincide within the working range of the speed. Then the number of processing channels is equal to the number of working frequencies. However, this method is rarely used because of the bulky equipment.

3. Simulation and Evaluation

Algorithm flowchart simulating the solution against "blind" speed:

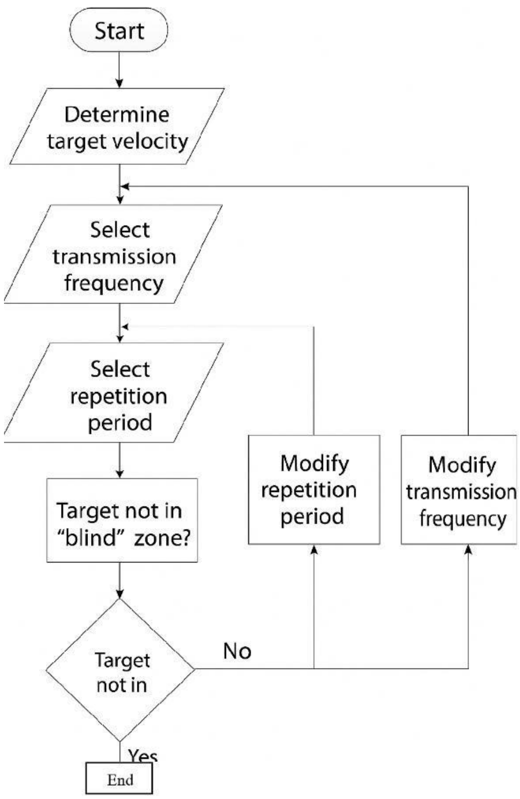

Figure 2 Algorithm flowchart simulating the solution against "blind" speed

Survey of ACX characteristics with ЧПВ

The normalized characteristic corresponds to the expression

$$A = \frac{|U_{ВЫХ}(V_r)|}{U_M} = \left|\sin\pi \cdot \frac{2 \cdot V_r}{\lambda_0} \cdot T_П\right| = \left|\sin\pi \cdot F_{Д0} \cdot T_П\right|$$

ACX characteristic when subtracted through the cycle once:

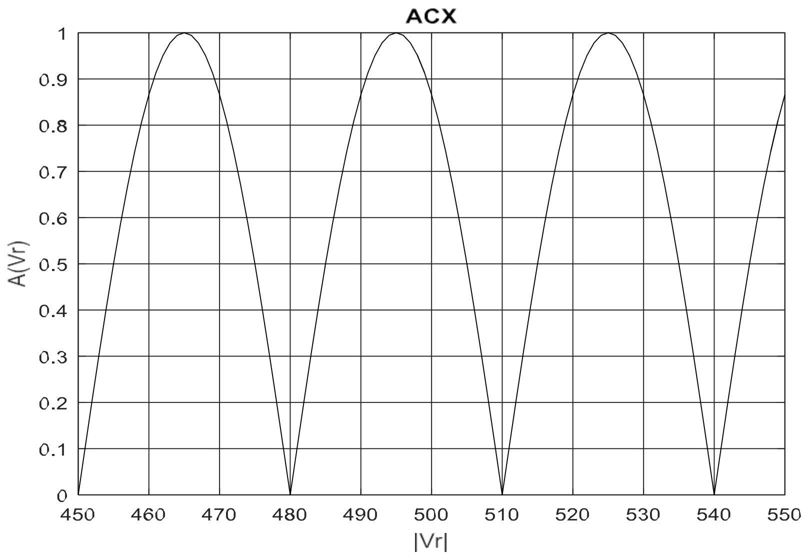

Figure 3 Amplitude - speed characteristics

ACX characteristic when subtracted over multiple cycles:

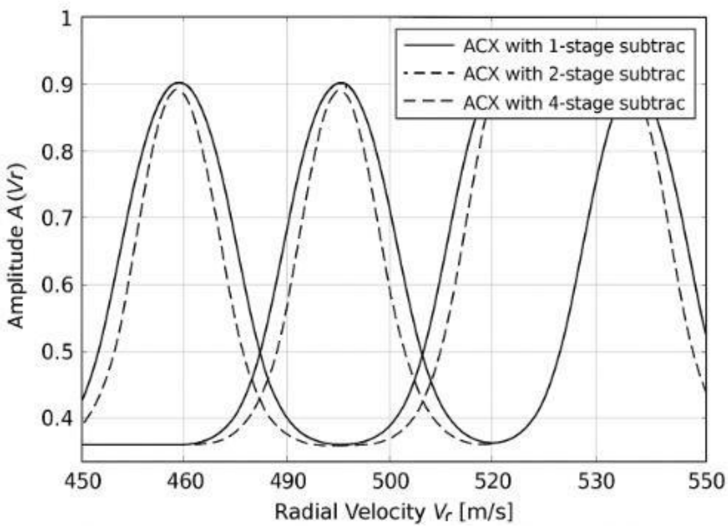

Figure 4 Amplitude - speed characteristics with 1-time, 2-time and 4-time subtraction diagrams

In the missile control station, two repetition periods are used in two modes:

- Slow target mode – МССЦ

- Fast target mode – БСЦ

In the slow target mode (МССЦ), the station's repetition period is ТП1 = 252 μs, ТП2 = 308 μs and corresponds to the velocity range Vr = (70 - 220) m/s. In the fast flight mode (БСЦ) ТП1 = 272 μs, ТП2 = 288 μs and corresponds to the velocity range Vr = (180 - 650) m/s.

Next, we examine the ACX curve characteristics in the modes:

• Slow-flying target mode – МСЦ: ТП1 = 252 μs, ТП2 = 308 μs, Vr = (70 - 220) m/s

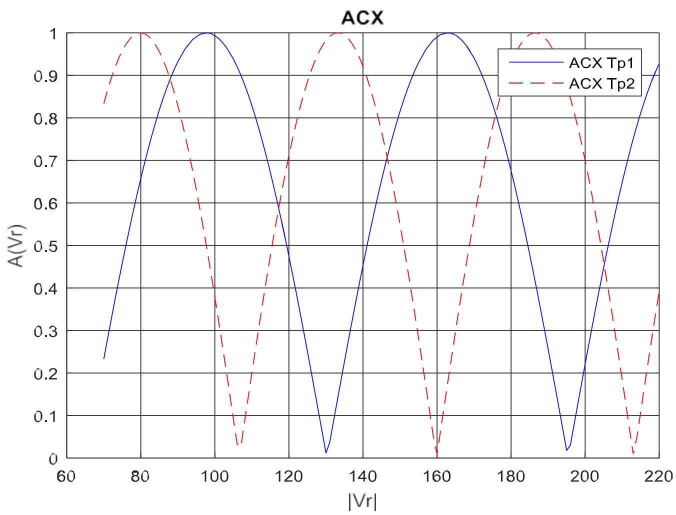

Figure 5 ACX characteristic using multiple repeating cycles in МСЦ mode

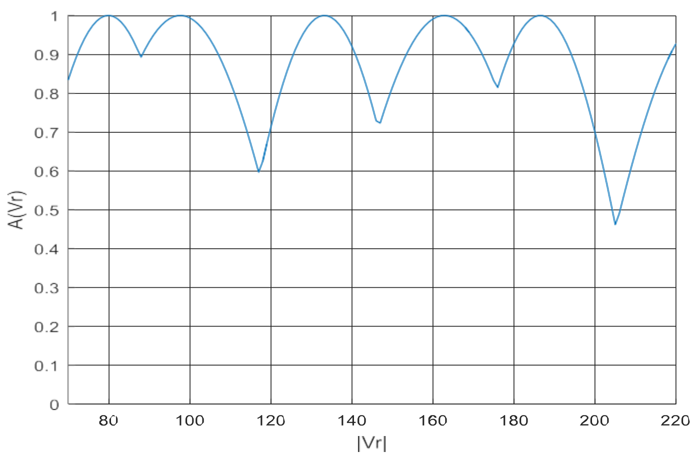

Figure 6 Selection characteristics in MSC mode

Fast flight target mode – BSC: ТП1 = 272 μs, ТП2 = 288 μs, Vr = (180 - 650) m/s

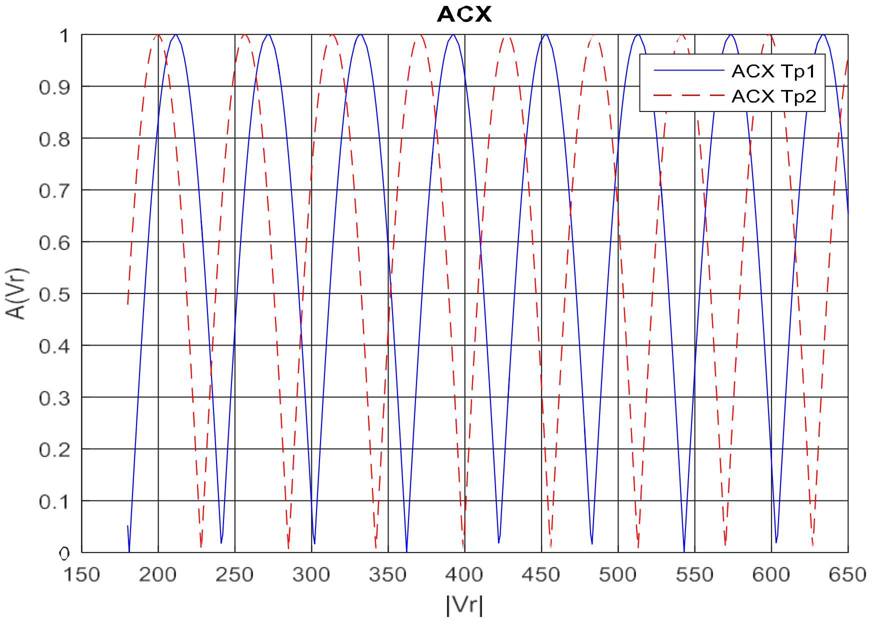

Figure 7 ACX characteristic using multiple repeating cycles in BSC mode

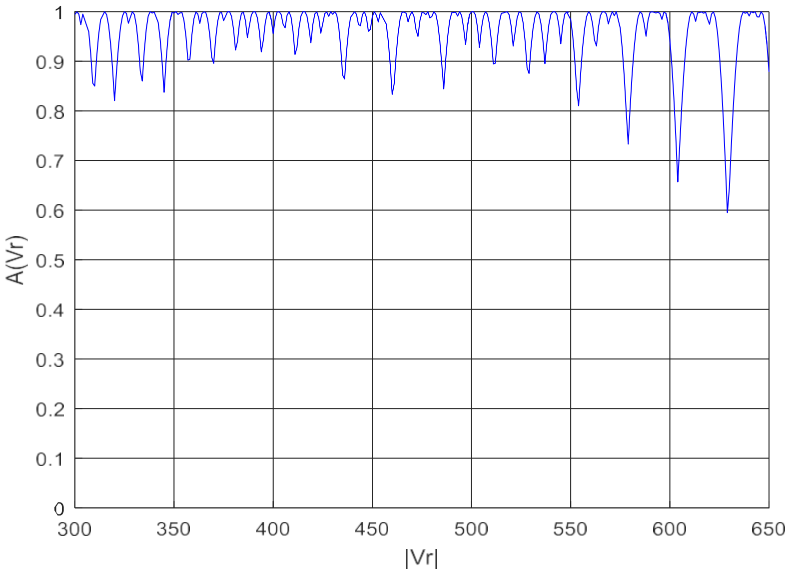

Figure 8 Selection characteristics in BSC mode

Through the survey of ACX characteristics in modes using the method of changing the repetition period of the probe pulse, we see that the missile has overcome the "blind" speed in the target velocity range. For the surface-to-air missile control station, 3 repetition periods of the probe pulse are used. The survey results of the ACX characteristics show more peaks, or more optimal velocity values, the smallest value of the concave part of the characteristic is 0.6 (Figure 8). Therefore, the efficiency of separating the moving target from the negative noise background is improved.

4. Conclusion

This study presented the development of an intuitive simulation interface designed to assist users in analyzing anti-blind-speed techniques for pulse-radar target detection systems. By enabling interactive adjustment of key parameters—specifically the pulse repetition period and transmitted signal frequency—the proposed tool allows users to directly observe how these variations affect the amplitude–velocity (ACX) characteristics of the moving-target indication (MTI) filter used in surface-to-air missile control radars.

Through simulation experiments conducted in MATLAB, the results clearly demonstrate that modifying the pulse repetition period has a significant impact on the formation and displacement of blind-speed zones. Users can therefore evaluate the effectiveness of different anti-blind-speed strategies and quantitatively examine how parameter variations mitigate or shift these undesired velocity intervals. The ability to visualize ACX characteristics across multiple operating modes provides an evidence-based foundation for improving radar detection performance in practical air-defense scenarios.

Overall, the study contributes a useful simulation framework that supports training, operational planning, and further research on MTI filtering and anti-blind-speed solutions in modern surface-to-air missile systems. Future work may integrate additional signal-processing algorithms, incorporate real-world radar data, or extend the interface for multi-radar cooperative evaluation.

Acknowledgments

The authors express their sincere appreciation to all individuals and institutions who indirectly contributed to the completion of this research

Declaration of Conflicting Interests

The authors declare that there are no conflicts of interest regarding the research, authorship, or publication of this article.

Funding

The author received no financial support for the research, authorship and publication of this article.

References

[1] M. I. Skolnik, *Introduction to Radar Systems*, 3rd ed. McGraw-Hill, 2002.
[2] M. Richards, *Fundamentals of Radar Signal Processing*, 2nd ed., McGraw-Hill, 2014.
[3] N. Levanon and E. Mozeson, *Radar Signals*. Wiley-IEEE Press, 2004.
[4] J. Ward, “Space-Time Adaptive Processing for Airborne Radar,” *MIT Lincoln Laboratory*, Tech. Rep. 1015, 1994.
[5] D. K. Barton, *Radar System Analysis and Modeling*, Artech House, 2004.
[6] B. R. Mahafza, *Radar Systems Analysis and Design Using MATLAB*, 3rd ed., Chapman & Hall/CRC, 2016.
[7] A. Charlish and K. Woodbridge, “Adaptive Pulse Repetition Frequency Selection for Radar Resource Management,” *IET Radar, Sonar & Navigation*, vol. 3, no. 4, pp. 349–357, 2009.