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THE CONCEPT OF DISRUPTING ANTI-RADIATION MISSILES IN A RADAR DECOY SYSTEM

KONCEPCJA ZAKŁÓCANIA POCISKÓW ARM W SYSTEMIE PUŁAPEK RADIOLOKACYJNYCH

Streszczenie

Toczące się obecnie na świecie konflikty zbrojne dowodzą ogromnej roli rozpoznania elektronicznego, które staje się jednym z podstawowych źródeł danych na temat przeciwnika i obszaru działań. Jednym z narzędzi walki radioelektronicznej, w której skład wchodzi rozpoznanie elektroniczne, są stacje radiolokacyjne, pełniące kluczową rolę w wykrywaniu, śledzeniu i identyfikacji przeciwników latających oraz w kierowaniu uzbrojeniem w celu zwalczania tych zagrożeń. Własne stacje radiolokacyjne są również celem przeciwnika. Pociski, które do tego służą, nazywa się pociskami przeciwradiolokacyjnymi. Jednym ze sposobów obrony jest modyfikacja pola elektromagnetycznego w otoczeniu chronionego radaru. Celem artykułu było przedstawienie modelu koherentnego zakłócenia pocisku przeciwradiolokacyjnego w systemie pułapek radiolokacyjnych radaru. Autorzy zastosowali analizę dostępnej literatury oraz przeprowadzili symulacje komputerowe w środowisku Matlab. Podsumowując, wskazano na istotną rolę, jaką pełnią na dzisiejszym polu walki pułapki radiolokacyjne.

Słowa kluczowe: walka radioelektroniczna, pułapka radiolokacyjna, przetwarzanie sygnałów, radiolokacja

Abstract

The ongoing armed conflicts in the world today demonstrate the huge role of electronic reconnaissance, which is becoming one of the primary sources of data on the enemy and the area of operations. One of the tools of radioelectronic warfare, which includes electronic reconnaissance, are radiolocation stations, which play a key role in detecting, tracking and identifying enemy aircraft and in directing armaments to combat these threats. The enemy's own radiolocation stations are also targeted. The missiles used to do this are called anti-radar missiles (ARM). One way to defend against them is to modify the electromagnetic field around the protected radar. The purpose of this article was to present a model of coherent interference of an anti-radiation missile in a radar trap system. The authors applied an analysis of the available literature and carried out computer simulations in the MATLAB environment. In conclusion, the important role played by radar decoys on today's battlefield was pointed out.

Keywords: radioelectronic warfare, decoy, signal processing, radiolocation

1. INTRODUCTION

Modern military operations demonstrate the enormous role of electronic reconnaissance, which is becoming one of the primary sources of data on the enemy and the area of operations. It acts in support of air defense systems, helping to detect, identify, track and neutralize air threats such as enemy aircraft, helicopters, drones, and ballistic or cruise missiles. One of the components of air defense are radiolocation stations, which play a key role in detecting, tracking and identifying enemy aircraft and in directing armaments to combat these threats¹.

Unfortunately, our own radiolocation stations are also a key target for the enemy to combat with Anti-Radiation Missiles (ARM). These missiles are designed to detect sources of electromagnetic emissions and homing in on them, with the goal of disabling our ability to detect and track enemy units. Consequently, there is a need to develop a defense system that will effectively repel anti-radiation missiles. One way to defend against this is to modify the electromagnetic field around the radar to be protected. This paper presents a model for coherent interference of an anti-radiation missile in a radar decoy system².

The purpose of the article is to propose a concept for a model for deploying decoys at the own radiolocation stations that make up the air defense system. The proposed model will be characterized primarily by high mobility, as indicated by the course and conclusions of the war in Ukraine so far. The article presents the necessary technical assumptions, signal models and simulations.

Theoretical research methods, such as the analysis and synthesis of information in the literature and source materials and the computer simulation method, were used to develop the article.

2. ANTI-RADIATION MISSILES

Anti-radiation missiles are missiles carried by combat aircraft, designed to destroy radiolocation installations and guided by electromagnetic radiation emitted by radar. They are equipped with a self-guided warhead of the passive type³. Its task is to detect the radiation emitted by the antenna of the operating radar and determine the angle of its position with respect to the longitudinal axis of the missile. This angle is then transformed into electrical signals that control the deflection of the missile's rudders, so that the missile's direction of flight coincides with that of the target. In this way the missile homing in on the radar antenna and then destroying it with a warhead explosion. Figure 1 shows a cross-section of the US AGM-88 HARM anti-radiation missile.

¹ S. Fontana, F. Di Lauro, *An Overview of Sensors for Long Range Missile Defense*, "Sensors" 2022, no. 22(24), p. 9871.

² J. Kwika, *Rozpoznanie radiolokacyjne - rzeczywistość i przyszłość Sił Powietrznych*, "Obronność – Zeszyty Naukowe Wydziału Zarządzania i Dowodzenia Akademii Obrony Narodowej" 2015, no. 4, p. 80.

³ K. Nicpoń, *Rakiety przeciwradiolokacyjne: zachód*, "Nowa Technika Wojskowa" 1996, no. 5, p. 32.

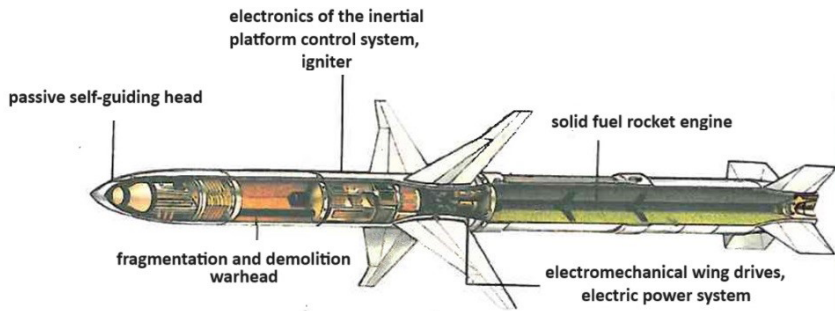


Fig. 1. Cross-section of the US AGM-88 HARM anti-radiation missile

Source: A. Ślesicka, *Model koherentnego zakłócenia pocisku ARM w systemie pułapek radiolokacyjnych*, master thesis, WAT, Warszawa 2017, p. 13.

The purpose of anti-radiation missiles is to completely neutralize or partially reduce the operation of enemy air defenses during an armed conflict in order to increase the security of our own troops⁴. The different ways in which anti-radar missiles attack radars depend on, among other things, the size and importance of air defense systems, as well as the location of specific radars that the adversary considers critical to achieving its goals⁵.

Taking into account the development of currently existing radar missiles, there are four main methods of combating radars⁶:

- a direct attack, in which an ARM missile rises to a very high altitude (at least several kilometers), then accelerates to maximum speed to prevent the radar operator from responding effectively to the attack in the last phase of flight (at a direct distance in front of the radar);
- ballistic attack, in which an ARM missile travels on a ballistic trajectory corrected by bearings from an onboard targeting warhead;
- delayed attack, the ARM missile, after reaching its maximum altitude (at least 20 km), shuts down its engines and begins descending on a parachute. When the reconnaissance and targeting warhead detects an object assigned for destruction, it discards the parachute and, with increasing speed, homing in on it;
- maneuvering attack, in which an ARM missile built in an aircraft-missile system moves along a programmed route and is designed to clear the flight path from air defense system radars.

⁴ Ibidem, p. 16.

⁵ S. Czeszejko, *Pociski przeciwradiolokacyjne – rozwój i ich stan obecny*, "Obronność – Zeszyty Naukowe Wydziału Zarządzania i Dowodzenia Akademii Obrony Narodowej" 2013, no. 1(5), p. 31.

⁶ J. Matuszewski, J. Pietrański, *Walka radioelektroniczna w radiolokacji*, WAT, Warszawa 2019, p. 196.

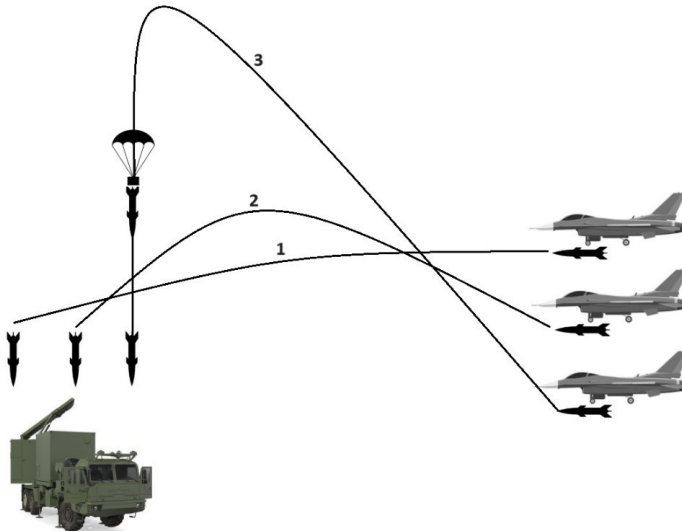


Fig. 2. Examples of ARM missile trajectories

Source: own elaboration based on: S. Czeszejko, *Pociski przeciwradiolokacyjne...*, op. cit., p. 31.

3. METHODS OF DISRUPTING THE MISSILE ARM

Ensuring effective radar protection ARMs is a key air defense challenge. There are several advanced methods of disrupting ARM missiles to minimize the risk of hitting them. Below are some important techniques for protecting radars from this type of threat⁷:

1. Decoys:

- The use of radar signal imitators, known as radar traps, can significantly interfere with missile receivers. By creating false signals, these traps make it difficult to accurately track the actual source of emissions.

2. Detection and tracking:

- Defense systems can focus on detecting and tracking ARM missiles using their own radars. Developing distress signals allows special radar modes to be activated, which in turn makes it more difficult for the missile's guidance receiver to maintain tracking.

3. Minimize broadcast time:

- Radar defenses can limit the timing of probe signals to reduce the risk of detection and targeting by a radar missile.

4. Signals difficult to detect:

- The use of signals that are difficult to detect and the variable sweep of space can make it difficult for missile receivers to identify and track radar signals.

⁷ M. Łuszczuk, *Wybrane problemy ochrony radarów przed rakietami antyradiolokacyjnymi*, "Problemy Mechatroniki" 2014, no. 5(16), p. 119.

This approach is designed to introduce misinformation into the decision-making process of missile guidance systems.

5. Continuous change of signal parameters:
 - Continuously changing the frequency and time parameters of the signal emitted by the radar is a key element of ARM missile defense. These changes, which are introduced in a pseudo-random fashion, make it difficult to precisely target the source of the emission.
6. Active GPS interference:
 - An effective countermeasure may be to actively interfere with GPS (Global Positioning System) and guidance receivers, but outside the radar's operating band. This is to stop the process of tracking the direction to the emission source by the ARM missile.

Comprehensive radar security against ARM missiles requires diverse and advanced defense strategies. A combination of these methods provides an effective barrier to hinder the effective operation of such missiles and protect vital radar systems from the threat.

In this article, a method based on the use of decoys is used to disrupt an ARM radar missile.

4. USE OF DECOYS TO PROTECT THE RADIOLOCATION STATION

Decoys, also referred to as radar imitators or electromagnetic imitators, are an integral component of the anti-radar missile (ARM) radar protection system. The main purpose of these devices is to generate electromagnetic signals designed to interfere with the operations of targeting systems used by the enemy⁸. In addition, these decoys are designed to introduce interference in the operation of self-guided anti-radiation missile systems launched by the enemy to destroy the radar.

The signals emitted by decoys are often referred to as signals masking the operation of a protected transmitter, such as radar. This high-tech solution is designed not only to interfere with the effectiveness of enemy targeting systems, but also to introduce disinformation into the missile's self-guidance systems. In practice, decoys create false signals, making the process of identifying and targeting the source of the emissions more difficult, which is crucial for effective defense against ARM missiles⁹.

So far, it is possible to find the use of an imitator of a radiolocation signal located on a trailer that is a component of a C-band capable Bystra radiolocation station. This is a solution of the Polish company PIT-RADWAR. It should be noted that it is a solution with only one imitator¹⁰. Taking the above into account, the goal of the authors of

⁸ J. Zou, K. Gao, S. Lu, E. Zhang, *Coherent Decoy Jamming Anti-radiation Missiles*, Proc. of 2013 IEEE Jordan Conference on Applied Electrical Engineering and Computing Technologies (AEECT) Amman, Jordan, 2013, p. 2.

⁹ J. Zou, K. Gao, E. Zhang, *Using radar echo to confront anti-radiation missiles*, "Electronic Letters" 2011, no. 47(5), p. 341.

¹⁰ <https://www.pitradwar.com/oferta/425,zdolna-do-przerzutu-stacja-radiolokacyjna-bystra> [access: 19.11.2023].

this publication is to develop a system to protect their own long-range radiolocation station, that is, a station operating in the X-band.

The following is a model for disrupting an ARM missile using two radar signal imitators placed at equal distances from the radar. Scientific research on radar jamming decoy issues indicates that the main influence on the effectiveness of ARM missile jamming is the number and placement of signal imitators. Decoys are very sensitive and sensitive to differences in the ratio of amplitude and phase between individual imitators¹¹.

Figure 3 shows a model of the radar protection structure. It is made up of a radar placed in the center of the system and two radar signal imitators placed at equal distances from the radar.

The model presented in this article was developed using a phase-based method of measuring the direction of signal arrival. For the adopted model and phase method, a system consisting of two decoys is required, consisting of an antenna and a receiver. The signals from the individual receivers are transmitted to a microwave phase detector, whose task is to indicate the value of the angle of arrival of the signal. A schematic of the system for measuring the angle of arrival of a signal is shown in Figure 4.

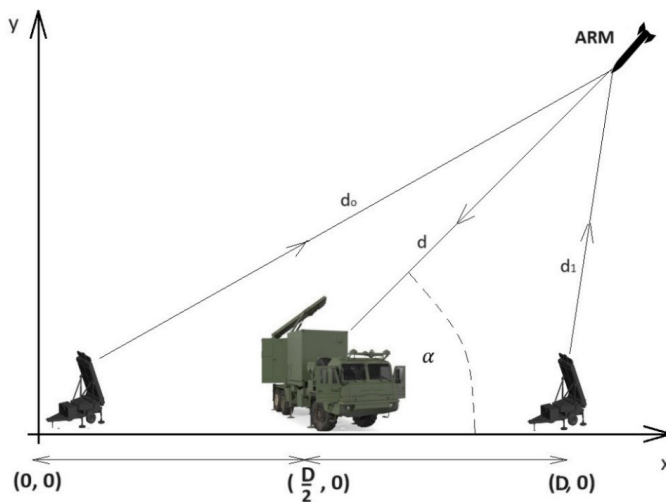


Fig. 3. Structure of the radar protection system

Source: own elaboration based on: M. Łuszczuk, *Wybrane problemy...*, op. cit., p. 119.

¹¹ J. Zou, K. Gao, S. Lu, E. Zhang, *The Angle Measurement Error Analysis of Near Field Phase Comparison under Coherent Sources*, "Journal of Information and Computational Science" 2011, no. 8(10), p. 2005.

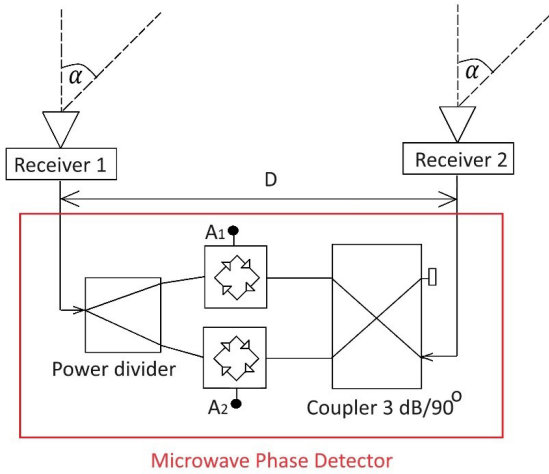


Fig. 4. Structure of the signal arrival angle measurement system

Source: own elaboration based on: A. Rutkowski, *Podzespoły i układy mikrofalowe – Wybrane zagadnienia i laboratorium komputerowe*, Warszawa 2010, p. 76.

The relationship for the angle of arrival of a signal is expressed as¹²:

$$\alpha = \arcsin \left[\frac{c}{2\pi f d} \arctg \left(\frac{A_1}{A_2} \right) \right] \tag{1}$$

where:

α – angle of signal arrival;

f – frequency of the received signal;

D – distance between antennas;

A_1 – the amplitude of the intermediate frequency signal at the receiver output coming from the first transmitter;

A_2 – the amplitude of the intermediate frequency signal at the receiver output coming from the second transmitter,

Taking the following designations:

d_0 – distance of the first signal imitator from the ARM;

d – the distance of the receiver from the ARM;

d_1 – distance of the second signal imitator from the ARM,

note that the difference in distance d_0 and d_1 affects the phase difference of the signals from the two imitators $\Delta\varphi$. For further analysis, it will be necessary to determine the distances d_0 and d_1 using the cosine theorem¹³:

$$d_1^2 = d^2 + \left(\frac{D}{2}\right)^2 - 2d\frac{D}{2}\cos\alpha \tag{2}$$

¹² A. Rutkowski, *Podzespoły i układy mikrofalowe...*, op. cit., p. 76.

¹³ J. Zou, K. Gao, E. Zhang, *Inducing Anti-radiation Missile Safely under Coherent Decoy Based on VD-Kalman Filter*, The International Conference on Information Engineering and Computer Science (ICIECS2009), China, Wuhan 2009, p. 2708–2711.

$$d_1 = \sqrt{d^2 + \left(\frac{D}{2}\right)^2} - 2d\frac{D}{2}\cos\alpha \tag{3}$$

$$d_0^2 = d^2 + \left(\frac{D}{2}\right)^2 - 2d\frac{D}{2}\cos(180 - \alpha) \tag{4}$$

$$d_0 = \sqrt{d^2 + \left(\frac{D}{2}\right)^2} - 2d\frac{D}{2}\cos(180 - \alpha) \tag{5}$$

Received echoes of imitator signals are given as¹⁴:

$$E_1 = A_1 \left[\beta \cos\left(\omega_1 t + 2\pi f_1 \frac{d+d_1}{c}\right) + \cos\left(\omega_1 t + \varphi_0 + 2\pi f_1 \frac{d+d_0}{c}\right) \right] \tag{6}$$

$$E_2 = A_2 \left[\beta \cos\left(\omega_2 t + 2\pi f_2 \frac{d+d_1}{c}\right) + \cos\left(\omega_2 t + \varphi_0 + 2\pi f_2 \frac{d+d_0}{c}\right) \right] \tag{7}$$

where:

φ_0 – the initial phase difference between the signals from the two transmitters;

Ω – the ratio of the amplitudes of the signals from the two transmitters;

f_1 – intermediate frequency in the receiving path of the first signal ($\omega_1 = 2\pi f_1$);

f_2 – intermediate frequency in the receiving path of the second signal ($\omega_2 = 2\pi f_2$);

$\frac{d+d_0}{c}$ – the time for the signal to reach the receiver from the first transmitter;

$\frac{d+d_1}{c}$ – the time it takes for the signal to reach the receiver from the second transmitter.

Phase difference for both receiving tracks¹⁵:

$$\Delta\varphi_1 = 2\pi f_1 \frac{d_0-d_1}{c} + \varphi_0 \tag{8}$$

$$\Delta\varphi_2 = 2\pi f_2 \frac{d_0-d_1}{c} + \varphi_0 \tag{9}$$

Hence, the final received echoes of imitator signals can be written as¹⁶:

$$S_1 = A_1 \sqrt{1 + \Omega^2 + 2\Omega\cos(\Delta\varphi_1)} \cos\left(\omega_1 t + 2\pi f_1 \frac{d+d_1}{c} + \arctan\left(\frac{\sin\Delta\varphi_1}{\Omega+\cos\Delta\varphi_1}\right)\right) \tag{10}$$

$$S_2 = A_2 \sqrt{1 + \Omega^2 + 2\Omega\cos(\Delta\varphi_2)} \cos\left(\omega_2 t + 2\pi f_2 \frac{d+d_1}{c} + \arctan\left(\frac{\sin\Delta\varphi_2}{\Omega+\cos\Delta\varphi_2}\right)\right) \tag{11}$$

From here, one can determine the arguments of the cosine function that are the phase shift being sought¹⁷:

$$\varphi_1 = 2\pi f_1 \frac{d+d_1}{c} + \arctan\left(\frac{\sin\Delta\varphi_1}{\Omega+\cos\Delta\varphi_1}\right) \tag{12}$$

$$\varphi_2 = 2\pi f_2 \frac{d+d_1}{c} + \arctan\left(\frac{\sin\Delta\varphi_2}{\Omega+\cos\Delta\varphi_2}\right) \tag{13}$$

Assuming that the second intermediate frequency is twice the first frequency $f_2 = 2f_1$ and that the initial phase difference is $\varphi_0 = 0$:

¹⁴ J. Zou, K. Gao, S. Lu, E. Zhang, *The Angle Measurement...*, op. cit., p. 2005.

¹⁵ J. Zou, K. Gao, E. Zhang, *Inducing Anti-radiation...*, op. cit., p. 2708–2711.

¹⁶ Ibidem.

¹⁷ Ibidem.

$$\Delta\varphi_1 = 2\pi f_1 \frac{d_0 - d_1}{c} \quad (14)$$

$$\Delta\varphi_2 = 2\Delta\varphi_1 \quad (15)$$

Hence:

$$\varphi_2 = 2\pi 2f_1 \frac{d+d_1}{c} + \arctan\left(\frac{\sin(2\Delta\varphi_1)}{\Omega + \cos(2\Delta\varphi_1)}\right) \quad (16)$$

$$\varphi_2 - 2\varphi_1 = \arctan\left(\frac{\sin(2\Delta\varphi_1)}{\Omega + \cos(2\Delta\varphi_1)}\right) - 2 \arctan\left(\frac{\sin\Delta\varphi_1}{\Omega + \cos\Delta\varphi_1}\right) \quad (17)$$

Defining¹⁸:

$$G = \tan(\varphi_2 - \varphi_1) \quad (18)$$

$$H = \cos(\Delta\varphi_1) \quad (19)$$

where:

$$\tan(\varphi_2 - 2\varphi_1) = \frac{(\Omega^2 - \Omega)(\sin 2\Delta\varphi_1 - 2\sin\Delta\varphi_1)}{2\Omega(\Omega + 1)(\cos\Delta\varphi_1 + 1) \cos(\Delta\varphi_1) + (\Omega - 1)^2(\Omega + 1)} \quad (20)$$

By squaring the above equation and equating to zero, the result was obtained¹⁹:

$$\begin{aligned} & [G^2(\Omega + 1)^2 4\Omega^2 + 4(\Omega^2 - \Omega)^2] \cos^4 \Delta\varphi_1 - 8[(\Omega^2 - \Omega)^2 - \\ & G^2(\Omega + 1)^2 \Omega^2] \cos^3 \Delta\varphi_1 + G^2(\Omega + 1)^2 [4\Omega^2 + 4\Omega(\Omega - \\ & 1)^2] \cos^2 \Delta\varphi_1 + [4G^2 \Omega(\Omega + 1)^2 (\Omega - 1)^2 + 8(\Omega^2 - \Omega)^2] \cos \Delta\varphi_1 + \\ & G^2(\Omega + 1)^2 (\Omega - 1)^4 - 4(\Omega^2 - \Omega)^2 = 0 \end{aligned} \quad (21)$$

This is an equation of degree four, which must be reduced to the form²⁰:

$$\cos^4 \Delta\varphi_1 + B \cos^3 \Delta\varphi_1 + C \cos^2 \Delta\varphi_1 + F \cos \Delta\varphi_1 + J = 0 \quad (22)$$

where:

$$B = \frac{-8[(\Omega - 1)^2 - B^2(\Omega + 1)^2]}{B^2(\Omega + 1)^2 4\Omega + 4(\Omega - 1)^2} \quad (23)$$

$$C = \frac{B^2(\Omega + 1)^2 [4\Omega + 4(\Omega - 1)^2]}{B^2(\Omega + 1)^2 4\Omega + 4(\Omega - 1)^2} \quad (24)$$

$$F = \frac{4\Omega^2(\Omega - 1)^2 + 8\Omega(\Omega - 1)^2}{B^2(\Omega + 1)^2 4\Omega + 4(\Omega - 1)^2} \quad (25)$$

$$J = \frac{B^2(\Omega + 1)^2 (\Omega - 1)^4 - 4(\Omega^2 - \Omega)^2}{B^2(\Omega + 1)^2 4\Omega + 4(\Omega - 1)^2} \quad (26)$$

Next, construct a third-degree equation so that the root of x is real²¹:

$$x^3 - Cx^2 + (BF - 4J)x + (4CJ - F^2 - B^2J) = 0 \quad (27)$$

Defining new variables²²:

$$K = \frac{3(BF - 4J) - C^2}{9} \quad (28)$$

$$L = \frac{-9C(BF - 4J) - 27(4CF - F^2 - B^2J) + 2C^3}{54} \quad (29)$$

$$M = \sqrt[3]{L + \sqrt{K^3 + L^3}} \quad (30)$$

¹⁸ Ibidem.

¹⁹ Ibidem.

²⁰ Ibidem.

²¹ Ibidem.

²² Ibidem.

$$N = \sqrt[3]{L - \sqrt{K^3 + L^3}} \tag{31}$$

and $W = K^3 + L^3$, which is a distinguishing feature of:

if $W > 0$, we get one real element and the other two composite elements;

if $W = 0$, we get three real primes and at least two equal to each other;

if $W < 0$, we get all elements real and unequal to each other in value.

Elements of the third degree equation²³:

$$x_1 = M + N + \frac{1}{3}C \tag{32}$$

$$x_2 = -\frac{1}{2}(M + N) + \frac{1}{3}C + \frac{1}{2}i\sqrt{3}(M - N) \tag{33}$$

$$x_3 = -\frac{1}{2}(M + N) + \frac{1}{3}C - \frac{1}{2}i\sqrt{3}(M - N) \tag{34}$$

If all the elements of equation (28) are real, then in further calculations we consider the one for which all the coefficients of the equation below will be real²⁴:

$$H^2 + \frac{1}{2}(B \pm \sqrt{B^2 - 4C + 4x_0})H + \frac{1}{2}(x_0 \mp \sqrt{x_0^2 - 4J}) = 0 \tag{35}$$

The solution of the quadratic equation (35) is²⁵:

$$H = \cos(\Delta\varphi_1) \tag{36}$$

Transforming the relation (36), the phase difference sought was obtained²⁶:

$$\Delta\varphi_1 = \arccos(H) \tag{37}$$

Given the above relationships, it should be emphasized that the only parameters that can be influenced when building the above model are the distance over which the imitators D are spaced and the intermediate frequencies in the receiving paths of both imitators f_1 and f_2 . The task of the radar is to indicate the distance to the object d , while the task of the microwave phase detector is to determine the angle of arrival of the signal α based on the amplitudes of the intermediate frequency signals at the output of receivers A_1 and A_2 .

5. SIMULATIONS

In order to test the correctness of the developed model of ARM missile interference in the radar trap system, a series of simulations were performed in the Matlab environment, showing the influence of various parameters on the missile's flare effectiveness. The radar was assumed to operate at an X-band frequency of 10 GHz. The tests were carried out for different criteria. The effect of the direction of signal arrival, the distance between imitators and the intermediate frequency of the receiver on the value of the phase difference was compared.

²³ Ibidem.

²⁴ Ibidem.

²⁵ Ibidem.

²⁶ Ibidem.

The first simulation was to study how the length of the base, or the spacing of the signal imitators, affects the value of the phase difference error. The signal imitators are located at the same distance from the radar. The signal's angle of arrival is 60° , the receiver's intermediate frequency is 20 MHz, and the radar-missile distance was 2000 meters.

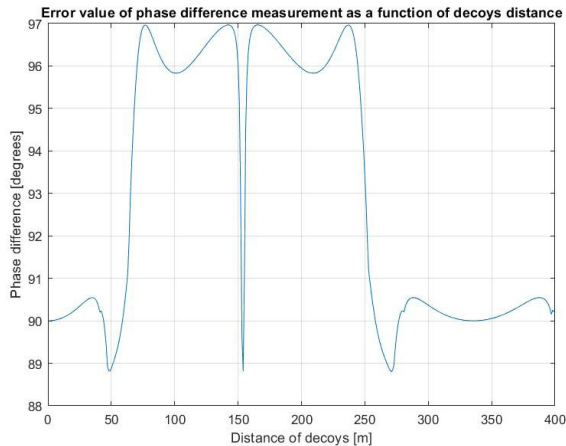


Fig. 5. Error value of phase difference measurement as a function of decoys distance

Source: own elaboration based on: M. Łuszczuk, *Wybrane problemy...*, op. cit., p. 119.

The possibility of detecting a radiolocation station by a missile at a distance of 2000 meters from the radar is most likely when the imitators are spaced 300 meters apart, i.e. when each imitator is 150 meters from the radar, as shown in Figure 5. The largest error in measuring the phase difference occurs for base lengths in the range of 70–140 and 160–220 and is about 7° .

In order to study what effect the angle of arrival of the signal has on the value of the phase difference measurement error, another simulation was performed, the result of which is shown in Figure 6. To perform the simulation, the receiver's intermediate operating frequency was assumed to be 20 MHz and the base length equal to 300 meters in the first case and 100 meters in the second.

The obtained characteristics shown in Figure 6 in the range of signal arrival angles from 0° to 180° are symmetrical with respect to the 90° angle. When the length of the base is 300 meters, the most accurate measurement of the phase difference was obtained at an angle of signal arrival of 60° , while the largest difference occurred in the range of signal arrival angles of 25° – 55° and 65° – 85° . With a change in the length of the base at a distance of 100 meters, the probability of successfully locating a radio station occurs for slightly different angles. In this case, the most accurate measurement of the phase difference was obtained at an angle of signal arrival in the range of 20° – 45° , while the largest difference occurred in the range of signal arrival angles equal to 45° – 80° . From the analysis of the characteristics, it can be seen that

for the spacing of the imitators at a distance of 100 meters, there are significantly larger deviations in the phase difference.

The purpose of the last simulation was to show the effect of the receiver’s intermediate frequency on the value of the phase difference measurement error. The simulation was carried out for the case of imitators spaced 100 and 300 meters apart. The angle of signal arrival was fixed at 60°.

The possibility of precise localization of the ground targeting system by the radar missile for the case of spacing the imitators of the radar signal at a distance of 300 meters is highly probable only for even harmonics. If the receiver is tuned to odd values the possibility of destroying the radar station decisively decreases. If the imitators are spaced at a distance of 100 meters, the probability of damage to the ground-based targeting system clearly increases.

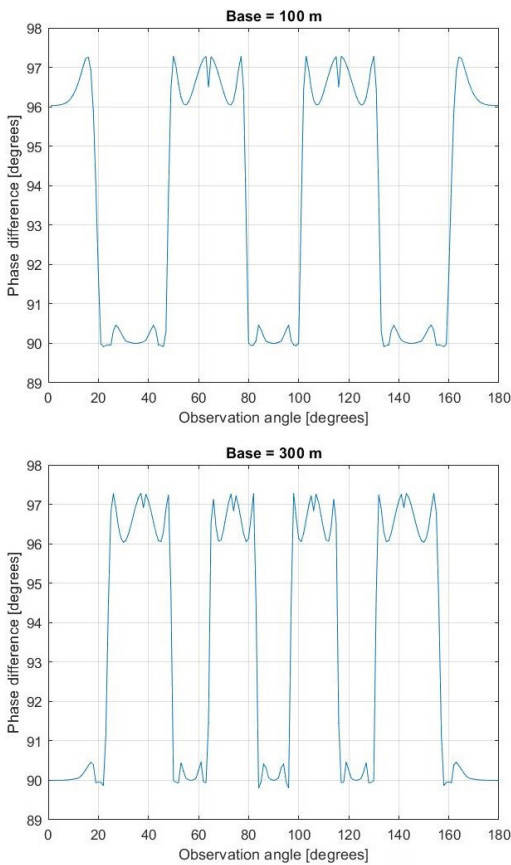


Fig. 6. Error value of phase difference measurement as a function of signal arrival angle

Source: own elaboration based on: M. Łuszczuk, *Wybrane problemy...*, op. cit., p. 119.

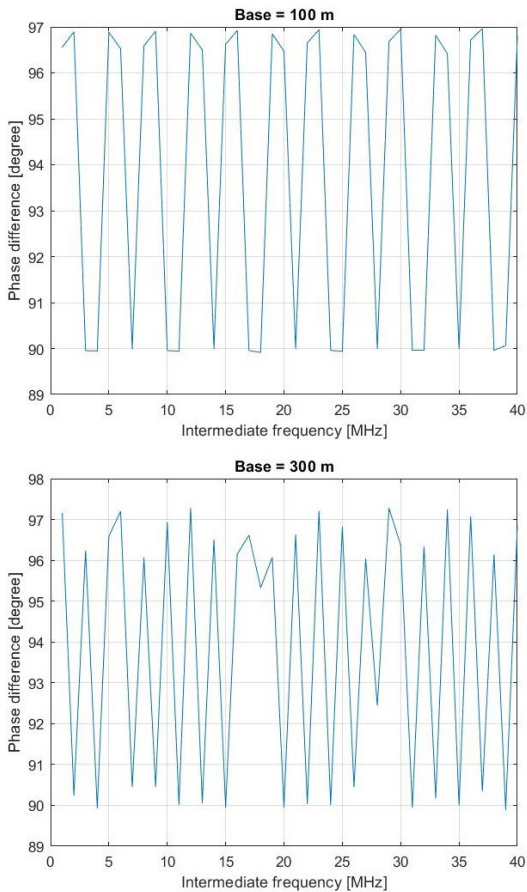


Fig. 7. Error value of the phase difference measurement as a function of the receiver's intermediate frequency

Source: own elaboration based on: M. Łuszczuk, *Wybrane problemy...*, op. cit., p. 119.

Parity with this choice of parameters for the model under study no longer has such a significant effect. For the first case of the length of the base, the error in the measurement of the phase difference is slightly more than 7° , i.e. the maximum error in the measurement of the location is equal to 245 meters, and for the second situation this value does not exceed 7° , i.e. the maximum error in the measurement of the location is 210 meters. In both cases, the missile was at a distance of 2 kilometers from the radiolocation station.

6. SUMMARY – CONCLUSIONS

This paper presents a model of coherent interference of an ARM missile in a radar trap system. Based on the adopted model, a series of computer simulations were developed in the Matlab environment to verify the developed model.

The developed model consists of two coherent imitators of radiolocation station operation placed at equal distances from the parent radiolocation station. The work uses the phase method of measuring the direction of signal arrival, in which information about the angle of signal arrival is obtained by determining the phase difference.

The simulation results confirmed the complex theoretical relationships, which are so closely interrelated that any change in one of the parameters, i.e. the angle of signal arrival, the distance between imitators and the intermediate frequency of the receiver, affects whether or not the radiolocation station is destroyed. In addition, it is difficult to unambiguously determine which parameter has a key effect on the effectiveness of anti-radar missile interference.

From the analysis of the presented characteristics, it was deduced that the system will be most effective, that is, it will fulfill its function of interfering with the projectile when:

- the distance between the imitators will be 300 meters;
- direction of arrival of the signal will be 40°;
- the receiver will be tuned to an intermediate frequency of 15 MHz.

For such selected values of system parameters, the angle measurement error will be 7°, which will translate directly into a maximum position measurement error of 245 meters.

The analysis of the model developed in this paper indicates that the use of additional confusion beacons is one of the key methods used to protect own radar stations. The proposed concept is a contribution to the currently ongoing research on the development of electromagnetic traps used to protect own ground radar stations.

Further scientific research by the authors will analyze the feasibility of using more imitators to protect their own radiolocation station. Unfortunately, this requires the development of a new geometry and spacing scheme for the imitators, as well as the development of a system for measuring the angle of arrival of the signal from more receivers than two.

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