Jamming Analysis and Simulation of Active Jamming on Pulse Radar Fuze

Dong Li*, Xiaofei Zhu, Xiaowei Shen, Zhenjie Zeng
Xi’an Research Inst. of Hi-Tech Xi’an, China

*Corresponding author e-mail: 1783676816@qq.com

Abstract. Pulse radar fuze is widely used at present. The jamming and anti-jamming of radar fuze have always been the focus of modern electronic countermeasures. The working principle of pulse radar fuze and the jamming mechanism of three typical active jamming to radar fuze is analyzed, and the jamming effect is simulated. The simulation results show that the pulse radar fuze has a certain anti-jamming ability to suppress radio frequency noise; The anti-jamming measures of variable period has a good anti-jamming effect to range deception jamming; After the density of dense false target jamming reaches a certain degree, it can exert an effective influence on the pulse radar fuze.

1. Introduction
Radar fuze is a commonly used fuze technology in rocket weapon equipment. According to the characteristics of radio wave, it can be divided into continuous wave radar fuze and pulse radar fuze [1]. Because of the limited volume, the radar fuze on missile weapon is usually pulse radar fuze. Document [2] summarizes the development status of foreign radio fuze jammers, it introduces the main types and technical performance of two kinds of foreign jammers. The American "guerrilla" jammers are radio frequency repeater jammers, while the Russian "SPR-2" jammers are suppressive jammers, from which we can see the mainstream jamming form of modern battlefield jammers. Document [3] analyses the anti-jamming performance of pulse radar against multi-jamming sources. Document [4] analyses the anti-jamming performance of radio frequency jamming, modulation jamming and other jamming modes to pulse Doppler radar fuze. Document [5] summarizes the common anti-jamming measures of pulse radar at present, such as agile frequency, variable pulse transmitting period, phase coding, etc. In many documents, few documents specialize in the jamming and anti-jamming effect of pulse radar fuze.

In this paper, the jamming mechanism of three kinds of active jamming to pulse radar fuze is analyzed, and the jamming effect on pulse radar fuze is given quantitatively by simulation. The simulation results can provide basis for the evaluation of the working ability of pulse radar fuze in complex environment and provide direction for performance improvement.

2. Pulse radar fuze

2.1. Altimetry principle of pulse radar fuze
The function of the fuze is to give the detonation signal at the right time to maximize the lethal effect of the projectile. The radar fuze is to measure the height of the projectile from the ground and give the
detonation signal at the specified height. Pulse radar fuze transmits pulse signal to the ground, and
calculates the distance between the projectile and the ground by measuring the time delay of the echo.

2.2. Emission pulse
In order to achieve good altimetry effect, the pulse period is stable and the front and back edges are
small. The ideal pulse signal is a rectangular signal, but in reality, if the front and back edges of the
pulse are less than one tenth of the pulse width, it can be regarded as the ideal signal.
The expression of the transmitted signal can be written as [4]:

\[ S(t) = A \cos(\omega t + \phi_0) \left( \frac{P_{\tau}}{2} \right) \delta(t - NT) \]  

Where \( A \) is the pulse amplitude, \( \omega \) is the carrier frequency, \( \phi_0 \) is the initial phase, \( P_{\tau} \) is a pulse
of width \( \tau \) and amplitude 1, \( T \) is the pulse repetition period, \( N \) is an integer, \( \delta(t) \) is Dirac function,
\( \alpha = \frac{\tau}{T} \) is defined as duty cycle.

2.3. Searching and tracking
The core part of the fuze terminal is the searching and tracking circuit. The main function of the
searching and tracking circuit is to turn to the tracking state after searching the echo signal and produce
the level signal with high correlation. When the height meets the requirements, the detonation signal is
given by comparing and judging.
Searching and tracking circuits need to meet several requirements:
1) Search the echo signal in time and accurately: If the echo signal cannot be searched in time, the
radar fuze may miss the best time to detonate.
2) Stable tracking: After the search circuit finds the echo signal, it turns to the tracking state. It
needs the tracking circuit to track the echo signal stably, so it cannot be easily lost.
3) To be able to give a good, stable and accurate signal with a high degree of correlation: The fuze
machine judges the time of detonation by the altitude signal, which requires the searching and tracking
circuit to give a more accurate and stable altitude signal. The detection target of the radar fuze
machine is more complex, if it encounters mountains, depressions, forests and other terrain, the altitude
signal cannot change dramatically and cause error detonation.

3. Jamming analysis of active jamming to fuze
According to the characteristics of modern radar countermeasure and pulse radar fuze, three kinds of
active jamming are selected for jamming research.

3.1. Radio Frequency Noise Suppression Interference
Radio Frequency Noise Suppression Jamming is a typical way of suppress jamming, which uses direct
amplification and emission of white noise or Gauss noise [7]. Generally speaking, this form of
interference power is difficult to achieve greater, but with the development of interference technology,
there are also high-power radio frequency noise jammers. The advantage of radio frequency noise is
that the interference principle is simple, the theory has a good masking effect, and it is a better
interference mode.
The mathematical expression of radio frequency noise suppression interference is [8]:

\[ J(t) = A_n(t) \cos(\omega_n t + \phi_n) \]  

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Where $A_r(t)$ is the envelope amplitude, Rayleigh distribution, $\phi_r$ is the phase process, and uniform distribution of $[0, 2\pi]$. They are independent of each other. The power spectrum of radio frequency noise is usually expressed as a rectangular power spectrum with the same bandwidth as the receiver.

$$P_{j_n}(\omega)=\begin{cases} \frac{N_o}{2} & \left|\omega \pm \omega_0\right| \leq \pi \Delta F \\ 0 & \text{else} \end{cases}$$  \hspace{1cm} (3)

Where $\frac{N_o}{2}$ is the bilateral power spectral density of the noise and $\Delta F$ is the bandwidth of the radio frequency noise are used. Therefore, the power of the radio frequency noise is:

$$P_{j_n} = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \frac{N_o}{2} d\omega = N_o \Delta F$$  \hspace{1cm} (4)

The fuze echo signal can be expressed as:

$$S_n(t) = A_r \cos((\omega_0 + \omega_d)t + \phi_r)$$

$$\ast\left[\frac{P_r}{T} (t - \tau) \otimes \sum_{-\infty}^{+\infty} \delta(t - NT_r)\right]$$  \hspace{1cm} (5)

Where $\tau_r = \frac{2(R_0 - v_r t)}{c}$ is the delay time, $R_0$ is the initial distance of the fuze, $v_r$ is the descending speed, $A_r$ is the echo pulse amplitude, $\phi_r$ is the echo phase and the $\omega_d$ is doppler angular frequency, the power of the echo can be deduced from the formula as follows:

$$P_r = \lim_{T \rightarrow \infty} \frac{1}{T} \int_{-T/2}^{T/2} S_n^2(t) dt = \frac{A_r^2 \tau_0}{2T_r}$$  \hspace{1cm} (6)

Therefore:

$$\frac{S}{N} = \frac{P_r}{P_{j_n}} = \frac{A_r^2 \tau_0}{2N_o \Delta FT_r}$$  \hspace{1cm} (7)

After the echo signal and noise are processed by the receiver, the IF signal is obtained as follows:

$$S_d(t) = \frac{1}{2} KA_r U_0 \cos(\Delta \omega + \phi_r - \phi_0)$$

$$\ast\left[\frac{P_r}{T} (t - \tau) \otimes \sum_{-\infty}^{+\infty} \delta(t - NT_r)\right] + J_{\omega_d}(t)$$  \hspace{1cm} (8)

Where $J_{\omega_d}(t)$ is the noise, $K$ is the coefficient of the receiver, $U_0$ is the carrier amplitude, $\Delta \omega$ is the medium frequency angular frequency. The power density of the noise item is:
So the power of the noise item is:

\[ P_{J_{\text{noise}}} = \frac{1}{2\pi} \int_{-\infty}^{\infty} \frac{1}{2} K^2 U_0^2 N_0 \cdot \frac{2\pi}{r_0} \text{d}f \leq \frac{2\pi}{r_0} \]

(9)

Where the bandwidth of the noise is \( \frac{2\pi}{r_0} \), equal to the bandwidth of the receiver filter.

The power of the echo term is:

\[ P_{J_{\text{echo}}} = \lim_{T \to \infty} \frac{1}{T} \int_{-\infty}^{\infty} S^2(t) \text{d}t = \frac{\tau_0 A_0^2 K^2 U_0^2}{8T_c} \]

(11)

Therefore, the SIR is:

\[ \frac{S}{N} = \frac{P_{J_{\text{echo}}}}{P_{J_{\text{noise}}}} = \frac{A_0^2 \tau_0^2}{8\pi N_0 T_c} \]

(12)

Because the processing of noise and echo is same in the receiver, the receiver gain has no effect on SIR, but the filter will change the power density of RF noise.

3.2. Distance deception jamming

Distance deception jamming is one kind of deception jamming, which produces false signals through electronic system to achieve the effect of deceiving fuze machine. By changing the delay between jamming signal and transmitting signal, the jammer makes the fuze mistakenly think that it has reached the specified height, so as to give the detonation signal in advance, or make the search and tracking circuit mistakenly track the jamming signal, and output the false height signal, so as to give the detonation signal in advance or later. The expression of distance deception signal can be written as follows:

\[ J_{N_d}(t) = \sqrt{P_{J_{\text{noise}}}} S_i(t - \tau_{N_d}) \]

(13)

Where \( P_{J_{\text{noise}}} \) is the transmitter power of jammer, \( S_i(t) \) is the transmitter signal expression of fuze, \( \tau_{N_d} \) is the delay time difference of jammer, there are two parts, one is the propagation time in the pulse path, the other is the processing time of the jammer [9].
Fig. 1. Range false target interference

\( \tau_r \) is the delay time for real target and \( \tau_{NA} \) is the delay time for false target.

The emergence of DRFM (Digital Radio Frequency Storage) technology facilitates the implementation of distance deception jamming. The jammer can quickly obtain the technical parameters of radar fuze and implement specific deception jamming to the fuze according to the demand.

3.3. Dense false target jamming

Dense false target jamming belongs to both repeater deception jamming and suppressive jamming. The difference between dense false target jamming and distance deception is that the pulse repetition period is very dense. The probability of searching jamming signal through distance gate is increased by a large number of jamming pulses, so the success rate is related to density of dense false target jamming and jamming pulse repetition cycle. The expression of dense false targets can be written as follows:

\[
J_{\text{na}}(t) = A_{\text{na}} \cos(\omega_{\text{na}}(t - \tau_{\text{na}}) + \varphi_{\text{na}}) \\
\ast [P_{\text{na}}(t - \tau_{\text{na}}) \otimes \sum_{n=1}^{2} \delta(t - nT_{\text{na}})]
\]

(14)

Where \( A_{\text{na}} \) is the jamming amplitude, \( \tau_{\text{na}} \) is the jamming delay, \( \varphi_{\text{na}} \) is the jamming phase and \( T_{\text{na}} \) is the repetitive period of the jamming pulse of dense false targets. It can be seen from the expression that dense false target jamming is actually the interception of the signal transmitted by the jammer to the fuze, and then forwarded out in different periods, \( T_{\text{na}} \) is much smaller than \( T_r \).

The effective jamming power calculation of dense false targets needs to know two points, one is the power of a single false target, and the other is the number of detected targets. Setting \( P_{\text{na}}(t) \) is the power of the first false target, \( m \) is the number of false targets detected in the total 2n cell, and the power of the effective false target is:
4. Simulation and Analysis

4.1. Simulation conditions and explanations
In order to facilitate the simulation test and more practical fuze machine, some assumptions and equivalents are made in the simulation.

Suppose the fuze adopts anti-jamming measures with variable launch period. In practice, some anti-jamming measures are taken by radar fuze machine. It is assumed that the fuze machine adopts anti-jamming measures with variable period to resist general deception jamming.

It is assumed that the interference signals are transponded. As mentioned above, DRFM technology is developing rapidly at present. The jammer can analyze, store and transmit after receiving the transmitting signal of the fuze. Some parameters of the jamming signal can be detected from the transmitting signal of the fuze.

Suppose that the probability of the fuze giving the detonation signal is less than 90%, it can be regarded as the jamming success.

The receiver has a limited amplitude effect, assuming that the normal echo is 1, when it is higher than 1.2, the receiver will limit the amplitude.

In the simulation experiment, the parameters of the pulse radar fuze are set up, and the missile-borne platform is set to work from the altitude of 8000m to the ground, and the jammer starts to work when the altitude is 7000m.

4.2. Simulation results and analysis
Figure 2 shows the relationship between the searching and tracking circuit and the echo signal when the radar fuze is working normally.
Figure 2 (a) is the search distance gate, red is the search distance gate and blue is the echo; Figure 2(b) is the state of the echo signal searched by the searching and tracking circuit, green is the search gate, red is the phase detector gate, responsible for tracking the echo, blue is the echo; 2(c) is the level signal which is not smoothed and highly correlated; 2(d) is level signal that has been smoothed and highly correlated. From the simulation diagram, it can be seen that the level value decreases as the height decreases, and when it is lower than a certain value, the detonation signal is given.

4.3. Simulation of radio frequency noise suppression jamming
Setting the frequency band of RF noise interference is equivalent to that of receiver filter. Figure 3 shows the simulation time domain diagram of echo and noise when SNR is - 10 dB, - 14 dB, - 20 dB, - 26 dB, respectively. Red is the echo and blue is the noise. As the noise increases, the echo is gradually submerged.
From -26dB to -18dB, the simulation is conducted 100 times each time, and Figure 4 is obtained. From the graph, it can be seen that when the signal-to-noise ratio is less than -22dB, the noise can interfere with the fuze effectively.

Because the peak power of the transmitting pulse of the fuze is large, the noise power of the radio frequency noise is larger than the peak power of the pulse in the whole pulse repetition period, so the average power of the noise is much larger than the average power of the transmitting signal, and the signal-to-noise ratio is smaller. This reflects that the pulse radar fuze has certain anti-jamming ability to suppress jamming.
4.4. Simulation of distance deception jamming
Setting the SIR to -6dB and simulate 100 times. The height position of the detonation signal is given by each fuze machine as shown in Figure 5. It can be seen from the graph, in each simulation, the fuze machine can give the detonation signal within the allowable range of error, and the interference can not achieve the deception effect.

The reason why the fuze has a good anti-jamming performance against distance deception jamming is that the fuze adopts anti-jamming measures with variable period. Because the period of transmitting pulse changes randomly, the jammer can not accurately predict the position of the search gate, and the distance delay time can not be determined, so it can not effectively jam.

4.5. Simulation of dense false target jamming
Setting the SIR is -6dB and the emission period of the false target jamming is an integer multiple of the pulse width, the density can be expressed by multiple. The lower the multiple, the more dense it is. Figure 6 shows the jamming effect of dense false targets on fuze machine at different multiples.
The interference density is 1-15 times, 100 times per simulation. Figure 7 shows the relationship between the density and the probability of detonation signal. It can be seen from the graph that when the density is less than 8 times, the false target jamming can jam the fuze effectively.

Fig. 6. Disturbance effects of different densities

Fig. 7. The success rate of detonation under different interference intensity
Although the anti-jamming measures with variable period can resist the false target jamming, when the density of the false target is large enough, the jammer can jam the fuze effectively.

5. Conclusion
In this paper, pulse radar fuze is taken as an object of study, three typical active jamming are selected to analyze the jamming mechanism of pulse radar fuze and simulate it. The experimental results show that the pulse radar fuze has a good anti-jamming effect on the general distance deception jamming when adopting the anti-jamming measures of variable period. However, with the development of technology, the jamming effect is better, the fuze can be jammed successfully by changing the jamming mode. For example, when the dense false target jamming reaches a certain density, the fuze can be jammed successfully. The simulation results are consistent with the actual situation, which has certain guiding significance for the jamming and anti-jamming of radar fuze in practice.

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