Research on Antenna Selection of Projectile-carried Communication Jammer

ZHANG Jie¹, MA Wenjun², ZHANG Xiaolei³

¹High Overload Ammunition Guidance and Control and Information Perception Laboratory Army Academy of Artillery and Air Defense Hefei, China
²91033 troops, Qingdao, China
³66736 troops, Beijing, China
e-mail: changchieh.love@163.com

Abstract. Focusing on the antenna selection of the projectile-carried communication jammer, this paper analyzed the requirements of the projectile-carried environment on the transmitting antenna from five aspects: antenna type, number of antenna parameters, signal propagation path, communication distance of the transceiver, calculation complexity of the radio’s sensitivity. The results show that in the process of designing and developing the projectile-carried communication jammer, it is suitable to select small whip antenna for projectile-carried communication jamming antenna.

1. Introduction
The projectile-carried communication jammer is a kind of jamming equipment, which uses the ammunition as the carrier, conventional artillery and rocket as the launching platform, and is quickly carried to the enemy target area to complete the communication jamming task [1][2][3]. Due to the limitation of projectile-carried space, the jamming power and size of the jammer can not exceed a certain range.

Therefore, in the actual development process of the projectile-carried communication jammer, the selection of a single component device must be considered. In this paper, based on the requirements of the projectile-carried environment for the transmitting antenna, the selection of the jamming antenna for the projectile-carried communication was discussed.

2. Requirements of projectile-carried environment on the category of transmitting antenna
According to the working frequency band, the communication antenna can be divided into short wave antenna, ultra-short wave antenna, microwave antenna, etc.; according to the directionality, it can be divided into isotropic antenna, directional antenna, etc.; according to the shape, it can be divided into line antenna, surface antenna, etc.

In terms of working frequency band: because the jamming targets of active communication jamming projectile are mainly enemy short wave and ultra-short wave frequency hopping communication radio stations [4][5][6][7][8][9][10][11], therefore, the antenna of projectile-carried communication jammer belongs to the category of short wave and ultra-short wave antenna;

Directionality: generally, the receiver of communication radio station aims the main lobe of antenna at the communication transmitter, therefore, for the directional antenna, the gain of the
receiver in the jammer direction is related to the field angle $\theta$ of the receiver to the transmitter and jammer$^{[12]}$. Compared with the fixed jamming on the ground, the jamming effect under the jamming environment of the projectile-carried communication will be affected by many uncontrollable factors. When determining the directionality of the antenna of the projectile-carried communication jammer, the isotropic antenna which is not affected by the $\theta$ should be selected.

In terms of shape: the space on the projectile must have a smaller antenna shape. At the same time, for a surface antenna, such as a parabolic antenna, the approximate formula for the gain is:

$$G(dBi) = 10\lg(4.5 \ast (D / \lambda_0)^2)$$  

In formula (1), $D$ is the paraboloid diameter; $\lambda_0$ is the central working wavelength; 4.5 is the statistical empirical data. It can be seen from formula (1) that the actual gain is also affected by the size of the specific paraboloid, which cannot be satisfied for the projectile-carried environment with extremely high space size requirements. Therefore, the linear antenna has more advantages than the surface antenna.

3. Requirements of projectile-carried environment for the number of parameters of transmitting antenna

Generally, the index parameters of antenna mainly include working frequency band, gain, lobe width, front to back ratio, standing-wave ratio, polarization mode and input impedance.

Five parameters, such as working frequency band, gain, standing-wave ratio, polarization mode and input impedance, are the necessary attributes of any type of antenna, while the necessity of two parameters, namely, lobe width and front to back ratio, needs to be considered.

For a directional antenna, the directivity diagram usually has two or more lobes, the one with the largest radiation intensity is called the main lobe, and the other is called the sidelobe.

There are two concepts about the width of the lobe: one is the angle between the two points where the radiation intensity reduces 3dB on both sides of the maximum radiation direction of the main lobe; the other is the angle between the two points with the radiation intensity reduced by 10dB on both sides of the maximum radiation direction of the main lobe. In the directivity diagram, the ratio of the maximum value of the front and back lobes is called the front to back ratio. The larger the front to back ratio is, the smaller the backward radiation (or reception) of the antenna is. For general antennas, the gain can be estimated as follows:

$$G(dBi) = 10\lg(32000 / (2 \\theta_{3dB,E} \times 2 \\theta_{3dB,H}))$$  

In formula (2), $2 \theta_{3dB,E}$ and $2 \theta_{3dB,H}$ are the width of the antenna's lobes in two main planes; 32000 is the statistical empirical data. It can be seen from formula (2) that the actual gain should also consider the influence of specific lobe width.

In the actual design and development process of the projectile-carried communication jammer, the key issues such as jamming power, specification size and jamming type need to be considered, as long as the projectile-carried antenna can successfully transmit the jamming signal to the enemy radio receiver.

If it is not affected by the specific lobe width or the front to back ratio, it is beneficial to build the projectile-carried communication jamming model and study the relationship between the jamming effect and the jamming signal parameters.

Therefore, two index parameters, such as the lobe width and the front to back ratio of the antenna, need not be considered.

4. Signal propagation path and requirements of projectile-carried communication jamming on signal propagation path

4.1. Signal Propagation Path

Because the jamming object of the projectile-carried communication jammer is the enemy short wave.
and ultra-short wave frequency hopping communication radio stations, the propagation path of the short wave and ultra-short wave signals were discussed here.

4.1.1. Multipath Propagation
In the ultra-short wave band, the wave will encounter obstacles (such as buildings or hills) in the process of propagation, which will reflect the wave. Therefore, there are many kinds of reflected waves (generally speaking, the ground reflected waves should also be included) arriving at the receiving antenna. This phenomenon is called multipath propagation.

Because of the multi-path transmission, the spatial distribution of the signal field strength becomes quite complex and fluctuates greatly. In some places, the signal field strength increases, while in some places, the signal field strength weakens. Also because of the influence of the multi-path transmission, the polarization direction of the electric wave changes. In addition, different obstacles have different reflection ability to the electric wave.

For example, the reflection ability of reinforced concrete buildings to ultra-short wave is stronger than that of brick walls. We should try our best to overcome the negative effects of multipath transmission, which is the reason why people often use spatial diversity technology or polarization diversity technology in communication networks with high communication quality requirements.

4.1.2. Diffraction Propagation
When there is a big obstacle in the path of propagation, the radio wave will bypass the obstacle and propagate forward. This phenomenon is called the diffraction of radio wave. The frequency of ultra-short wave is high, the wavelength is short, the diffraction ability is weak, and the signal strength behind tall buildings is small, forming the so-called "shadow area". The degree to which the signal quality is affected is not only related to the height of the building, the distance between the receiving antenna and the building, but also related to the frequency.

For example, there is a building with a height of 10 meters. At a distance of 200 meters behind the building, the received signal quality is almost unaffected, but at 100 meters, the received signal field strength is significantly weaker than that without the building. Moreover, for 216-223 MHz RF signal, the received signal field strength is 16 dB lower than that without building, and for 670 MHz RF signal, the received signal field strength is 20 dB lower than that without building.

If the height of the building increases to 50m, the field strength of the received signal will be affected and weakened within 1000m from the building. That is to say, the higher the frequency, the higher the building, and the closer the receiving antenna is to the building, the greater the signal strength and communication quality will be affected; on the contrary, the lower the frequency, the shorter the building, and the farther the receiving antenna is from the building, the less the impact will be.

Therefore, when choosing the base station site and erecting the antenna, it is necessary to take into account all kinds of possible adverse effects of diffraction propagation and all kinds of factors affecting diffraction propagation.

4.1.3. Ground Reflected Wave
The electric wave emitted by the transmitting antenna directly to the receiving point is called direct wave; the electric wave emitted by the transmitting antenna pointing to the ground, which is reflected by the ground and reaches the receiving point, is called reflected wave.

Obviously, the signal of receiving point should be the combination of direct wave and reflected wave. The combination of electric waves will not be algebraic summation as simple as \(1 + 1 = 2\), and the result will vary with the difference of wave path between the direct wave and the reflected wave.

When the wave path difference is an odd multiple of half a wavelength, the direct wave and the reflected wave signal are added together to form the maximum; when the wave path difference is a multiple of a wavelength, the direct wave and the reflected wave signal are subtracted to form the minimum. It can be seen that the existence of ground reflection makes the spatial distribution of signal
strength very complex.

4.2. Requirements of Signal Propagation Path for Projectile-carried Communication Jamming

Skywave propagation is the main mode of shortwave propagation, but the frequency of skywave is very time-varying. Influenced by the change of ionosphere, communication distance and direction, altitude, antenna type and other factors, even if the same set of radio and antenna is used and different frequencies are selected, the communication effect may vary greatly[13][14].

For example, at night, in a circular region at a certain distance from the antenna, there are both sky waves and ground waves with similar intensity, which interfere with each other, resulting in serious fading phenomenon; in the short wave sky wave propagation mode, the jammer is subject to the same restrictions as the communication radios, and the propagation path between the transmitter and receiver is generally different from the jammer link[4].

Therefore, when we focus on the relationship between the performance of projectile-carried communication jamming and signal parameters, in order to facilitate the construction of the model of projectile-carried communication jamming system, in order to make the results more targeted and reliable, we can ignore those factors that are not controllable or can not be accurately simulated. For the sake of simplification, generally in the research of tactical FH radio, the two ends of communication are only short-range communication, mainly using the way of ground wave propagation. That is to say, from the point of view of projectile-carried communication jamming, no matter the enemy short wave tactical frequency hopping radio or the enemy ultra-short wave tactical frequency hopping radio, only the direct wave is used as the main energy carrier of the communication signal, and the direct wave propagation mode in the ground wave propagation is adopted[15][16][17].

At the same time, the ground wave antenna includes whip antenna, inverted L-shaped antenna, T-shaped antenna and so on. The electromagnetic wave emitted by these kinds of antenna is isotropic, which is often used in short-range communication. According to the basic principle of antenna selection during short wave propagation[13], for the enemy short wave tactical frequency hopping radio, its communication antenna is generally a small whip antenna, and the personal carrying radio of short wave band can only use a short whip antenna when communicating in the road. Because of the high frequency and short wavelength, the antenna of ultra-short wave communication can be made very small, usually vertical whip antenna.

5. Communication distance requirement of projectile-carried communication jamming environment to enemy transceiver radio

According to the references [2], [3], [18], [19], the jamming distance of the communication jamming projectile is between 700m and 3000m, which shows that the jamming power of the projectile-carried communication jammer is small. Compared with the ultra-short wave radio and the short wave radio, the transmitting power is less than 10w and the communication distance is at least 10 kilometers, whether the jamming distance or the jamming power of the communication jamming projectile is small.

Therefore, as long as the relationship between the jamming performance and different jamming signal parameters can be verified, the conclusion can lay a technical foundation for the subsequent development of the projectile-carried communication jammer for different launch platforms.

The attenuation of ground wave is closely related to the working frequency. The higher the frequency is, the greater the attenuation is. On the sea, the communication distance can reach up to 1000km. On the land with relatively poor electrical performance, the communication distance is only tens of kilometers[20]; when the wavelength is 10-50m, the maximum range of ground wave propagation is 10km[21]. Generally speaking, the ground wave can be transmitted as far as 30km. A pair of 3-meter-long whip antenna with 25w-50w radio station can only reach 20 kilometers at most[13].

The surface wave attenuation of ultra-short wave is very fast, so it can't be transmitted by surface wave in a long distance. Obviously, due to the curvature of the earth, there is a limit of the direct
viewing distance $R_{\text{max}}$. It is self-evident that when using ultra-short wave for communication, the receiving point should fall within the maximum direct viewing distance $R_{\text{max}}$ of the transmitting antenna. Influenced by the radius of curvature of the earth, the relationship between the limiting direct viewing distance $R_{\text{max}}$ and the height $H_T$ and $H_R$ of the transmitting antenna and the receiving antenna is as follows:

$$R_{\text{max}} = 3.57 \times (\sqrt{H_T} + \sqrt{H_R})(\text{km}) \quad (3)$$

It can be seen from the above analysis that, in the actual design and development of the projectile-carried communication jammer, in order to verify the relationship between the projectile-carried communication jamming performance and the specific signal parameters, from the perspective of operability, we can assume that the transmitting power is between 5w-10w and the communication distance is between 3-5km when selecting the jammed enemy frequency hopping radio.

6. Requirements of projectile-carried communication jamming environment for the complexity of receiver sensitivity calculation of enemy radio station

When the communication distance of the enemy receiving and transmitting radio station is the maximum $R_{\text{max}}$, the signal power of the receiving antenna of the communication receiver is its minimum receiving power $P_{r(\text{min})}$, or the signal-to-noise ratio of the receiving antenna of the communication receiver is its minimum receiving signal-to-noise ratio $S_{N(\text{min})}$, that is, sensitivity $^{[22]}$.

$$P_{r(\text{min})} = P_G \varphi (R_{\text{max}}) \cdot q_{rt} \quad (4)$$

$$S_{N(\text{min})} = \frac{P_G \varphi (R_{\text{max}}) \cdot q_{rt}}{K T \Delta f_r F_n} \quad (5)$$

Among them,

$P_r, G, \varphi$ are the power and gain of communication transmitter;

$\varphi$ is the power loss of communication line;

$K$ is Boltzmann constant, $T$ is absolute temperature. Generally, $K T = 4 \times 10^{-21} W / Hz$;

$F_n$ is the noise factor.

$\Delta f_r$ is the receiver bandwidth.
In the study of the relationship between the jamming performance of projectile-carried communication and the specific signal parameters, it is sometimes necessary to check whether the receiving radio station receives normal communication signals or jamming signals, which will involve the calculation of the sensitivity of the radio station.

It can be seen from formula (4) or (5) that as long as the relationship between the jamming performance of projectile-carried communication and different jamming signal parameters can be verified, the conclusion can lay a technical foundation for the subsequent development of projectile-carried communication jammer for different launch platforms, based on the principle of operability and more pertinent conclusion, we hope that the simpler the calculation process of sensitivity is, the better.

To sum up, the antenna type whose gain is not affected by the specific angle or other parameters should be selected, and the gain is better to be constant.

7. Conclusions

According to the requirements of the projectile-carried communication jamming environment on the transmitting antenna, the signal propagation path and the communication distance of the jammed radio station, it can be seen that the communication antenna of the frequency hopping radio station of the jammed enemy is a small whip antenna. Therefore, in the process of designing and developing the projectile-carried communication jammer, it is suitable to choose the small whip antenna as the antenna of the projectile-carried communication jammer.

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