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Research on Ground Motion Metal Target Based on Rocket Projectile by Using Millimeter Wave Radiometer Technology

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Abstract: How to detect the ground motion metal target effectively is an important guarantee for precision strike in the process of Rocket Projectile flight. Accordingly and in view of the millimeter-wave radiation characteristic of the ground motion metal target, a mathematical model was established based on Rocket Projectile about millimeter-wave detection to the ground motion metal target. Through changing various parameters in the process of Rocket Projectile flight, the detection model was studied by simulation. The parameters variation and effective range of millimeter wave radiometer were obtained in the process of rotation and horizontal flight. So a certain theoretical basis was formed for the precision strike to the ground motion metal target. *Copyright © 2014 IFSA Publishing S. L.*

Keywords: Millimeter-wave radiometer, Rocket Projectile, Metal Target, Detection, Parameters variation.

1. Introduction

With the development of military technology, much higher requirements to detection system of the weapons are brought forward for the new war mode, meanwhile, the detection capabilities, the target identification and the attack ability of precision-guided weapons are increasingly demanded to be improved so as to accurately identify and determinate the target and then choose to attack it in the complex battlefield environment. Rocket projectile, as a new type of ammunition used in smart modern weapons, has attracted the attention to many countries because of its own advantages, such as easy to carrying, intelligent wireless data transmission and multi-mode triggering, a number of countries like the United States and Russia put a good deal of effort into this kind of ammunition [1]. It has important functions that a wide range of search, surveillance, damage assessment, and attack the target by using bidirectional data link to transport the battlefield information [2-3], which can drive modern warfare into a higher mode strategy. It is crucial to detect the various performance parameters of rocket projectile accurately so as to be precision-guided in the modern science and technology society, still it is an urgent task on the overall design of the rocket projectile [4].

In the near sensing techniques field, the wavelength of millimeter wave usually refers to electromagnetic wave with a length between 1 and 10 millimeter and with frequency ranging from 30 to 300 GHz. Compared to infrared and laser, millimeter-wave detection has many advantages, which has not only high precision and strong anti-interference, but also the ability of all-weather working and strong penetrating power, what’s more, millimeter wave also has a light weight, small size, good performance, low cost and so on. Passive millimeter wave system recognizes target by relying on angle measurement and target emissivity differences, which can overcome the target flicker effect that will exist when active millimeter wave systems detect at short range, the target can be identified and located accurately [5]. According to the different radiation characteristics that the millimeter wave radiometer exhibit between different metal targets, once identified as the enemy metal target, it can be precisely struck and destroyed immediately.

2. Application Principle of Passive Millimeter-wave Radiometer

2.1. Characteristics of Millimeter-wave Radiometer

Metal target detection is mainly based on the fact that millimeter-wave has better discrimination ability of radiation characteristics of the metal and other substances to determine the presence of metal targets.

As long as all of the matter in nature is in absolute zero above, the entire electromagnetic spectrum will spontaneously radiate outward the electromagnetic energy (namely electromagnetic waves). It is the electromagnetic waves that the radiation energy of objects can be expressed as apparent temperature [6]. When the millimeter wave radiometer is applied to detect metal targets, the radiation temperature is detected to be zero no matter what environment it is because the millimeter-wave radiation rate of the metal target is close to zero, so the metal object can be determine. The emissivity of typical ground object surface is showed in Table 1 [7]. This paper calculates the temperature of the antenna according to their radiation characteristics.

Table 1. The emissivity of typical ground object surface.

Terrain \ Wavelength	3 mm	8 mm	3 cm
Metal surface	0	0	0
Water surface	0.63	0.63	0.38
Dry sand	0.83	0.86	0.90
Pitch	0.98	0.98	0.98
Meadow	1.0	1.0	1.0
Concrete	0.92	0.92	0.86

2.2. Principle of Millimeter-wave Radiometer Radiation

When radiometer antenna scans the metal target, the antenna temperature is known:

$$T_{BT} = \rho_T T_s + \rho_T T_{at}, \quad (1)$$

where ρ_T is the metal target reflection coefficient.

And temperature near the antenna radiation

$$T_{Bg}(\theta,\phi,p_i,\Delta f) = \rho_g(\theta)T_s + \varepsilon_g(\theta)T_g + \varepsilon_{at}(\theta)T_{at} + \rho_g(\theta)T_{at}\varepsilon_{at},$$

contrast ratio between ground targets and the metal is attainable

$$\begin{aligned}\Delta T_T &= T_{Bg}(\theta,\phi,p_i,\Delta f) - T_{BT} \\ &= \rho_g(\theta)T_s + \varepsilon_g(\theta)T_g + \varepsilon_{at}(\theta)T_{at} \\ &+ \rho_g(\theta)T_{at}\varepsilon_{at}(\theta) - \rho_T T_s - \rho_T T_{at}\varepsilon_{at}(\theta)\end{aligned}, \quad (2)$$

In order to analyze conveniently, sky is assumed to be cloudless, namely T_{at}=0, the above equation can be reduced to

$$\Delta T_T = \rho_g(\theta)T_s + \varepsilon_g(\theta)T_g - \rho_T T_s, \quad (3)$$

The ground metals (such as metal, tanks) targets can be identified after ΔT_T is calculated [6, 8-9].

3. Building Rockets Mathematical Models

The rocket projectile is dexterous maneuvering and flies fast, besides, its interior is equipped with a sensor device. As a flight carrier, the antithetic formula millimeter wave radiometer is placed in the head of projectile bodies. It is based on radiation characteristic features of this kind of ammunition and radiometer millimeter wave to detect metal targets on the ground, a mathematical model is shown in Fig. 1.

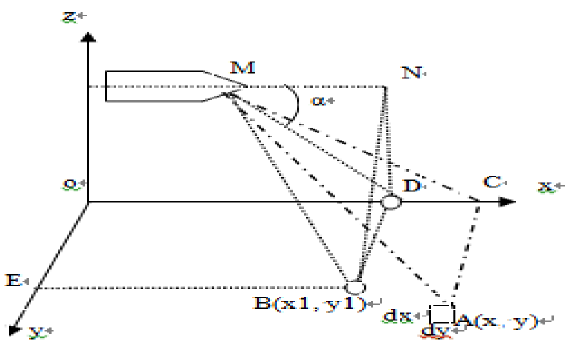

Fig. 1. Rocket Projectile mathematical model.

Rocket projectile is always maintaining a certain altitude detection during its flight, in accordance with the direct-fire and three point guidance low-level blow flight stretch trajectory evolved to hedgehopping upper armor attack trajectory. When the rocket flew over the target identified as an enemy metal target, proximity fuze detonates the warhead, the warhead formatting jet hit toward the top goal at a constant inclination angle speed [10]. If the projectile is considered as a rigid body, the space motion will be seen as the synthetic motion that center of mass move and the body rotates around the center of mass, otherwise it is easily deformed by aerodynamic force effect.

The quality of rocket projectile decreases due to constant fuel consumption, so the movement of the projectile is more complex than rigid body motion, To help make things easier, considering the movement of rocket projectile and target as particle motion at one point, namely curing parameters, mathematical modeling and simulation is developed at the point that rocket projectile detect metal targets during terminal guidance under ideal conditions.

According to the millimeter wave theory, metal targets will be identified if ΔT_T is detected, when scanning the metal target, antenna temperature change as followed:

$$\Delta T_A = \frac{1}{4\pi}(\int_{4\pi} \Delta T_T G(\theta,\phi) d\Omega \tag{4}$$

When the rendezvous case that radiometer detect the metal targets is shown in Fig. (2.1), H is the height of antenna away from the XY plane, D is the projection of a metal target A (x, y) onto the x-axis, metal targets with temperature contrast ΔT_T are in the XY plane. Wave beam millimeter wave radiometer scans target in the XY plane at α angle, the amount of change of rotation angle is β. Metal target differential unit is *dxdy*. Fig. 1 can be expressed as:

$$\begin{cases} l_2 = H / \cos\beta \\ x_1 = H \tan\beta \\ y_1 = l_1 \cdot \tan(\frac{\pi}{2} - \alpha) \\ s_1 = l_1 / \cos(\frac{\pi}{2} - \alpha) \end{cases}, \tag{5}$$

$$\begin{cases} s_2 = \sqrt{(x-x_1)^2 + (y-y_1)^2} \\ s_3 = \sqrt{x^2 + y^2 + h^2} \\ \theta = ar\cos(s_1^2 + s_3^2 - s_2^2)/(2s_1 s_3) \\ f = e^{-bs^2} / s_1^3 \end{cases}, \tag{6}$$

the followed formula can be obtained

$$\begin{aligned} \theta = {} & \cos\beta\cos(\frac{\pi}{2}-\alpha) ar\cos[\frac{H^2}{\cos^2\beta\cos^2(\frac{\pi}{2}-\alpha)} \\ & + 2Hx\tan\beta + \frac{2Hy\tan(\frac{\pi}{2}-\alpha)}{\cos\beta} - \frac{H^2\tan^2(\frac{\pi}{2}-\alpha)}{\cos^2\beta}, \\ & - H^2\cos^2\beta] \div [2H(x^2+y^2+H^2)^{1/2}] \end{aligned} \tag{7}$$

Then formula (7) is put into formula (4) and making unit unified, it is getting as follows:

$$\begin{aligned} \Delta T_A = {} & \frac{-10^3 G_0 H \Delta T_T}{4\pi} \cdot \\ & \int_{x_1}^{x_1+l}\int_{y_1}^{y_1+w} \frac{\exp(-bs^2)\cos^3\beta\cos^3(\frac{\pi}{2}-\beta)}{H^3} dydx \end{aligned}, \tag{8}$$

Integration showed that the range of integration depends on the rectangular target. Target orientation is long and short sides respectively parallel to the coordinate system x and y axes. Targets scale is l in the x direction and w in the y direction, target can't be detected by the radiometer until it is positioned the desired target position determined by the selection of x and y values which is referred to the antenna.

4. Detection and Simulation to Metal Targets

According to the mathematical model of rocket projectile shown in Fig. 1, there is a flat metal target B (x_1, y_1) on the ground background, and simulating an unknown metal motion target A (x, y) based on formula (8), set the radiometer parameter equal to Antenna Gain is G_0=32.041 dB, 3 dB beamwidth of antenna is θ_{3dB}=7.5°, normal the angle between the direction of radiometer and the normal of ground is θ_F=30°, azimuth is α=0°, offset is d=0 m the contrast of the target and background is 50 degree, rocket projectile flies horizontally at a constant rotation speed of 40 rad/s, sampling interval is 0.1875 ms, The moving metal targets sized at 7.9×3.65 m^2 were scanned by antenna beam of radiometer at a height from 15 m to 25 m, the output waveform in case of any intersection is simulated according to equation (8). It is simulated by MATLAB software, and the output waveform is shown in Fig. 2 after radiometer rotates a circle. There is some external interference in the space motion, and the upper structure of metal target has uneven surface, such as turret, etc. Therefore, the simulated waveform is irregular and not smooth, as shown in Fig. 3.

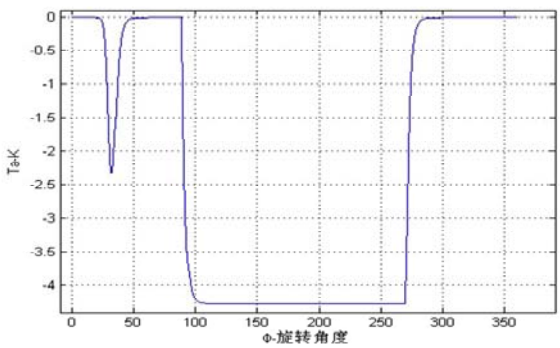

Fig. 2. Millimeter wave detection to metal target of output waveform.

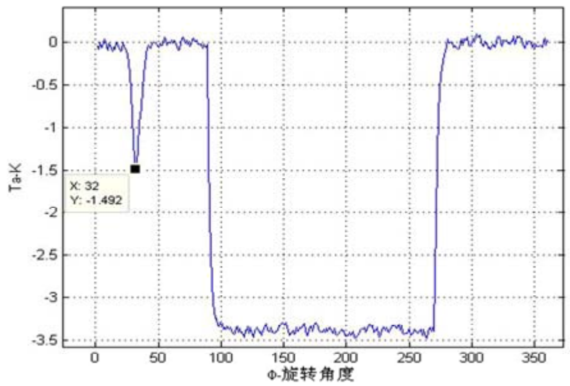

Fig. 3. After interference detection output waveform.

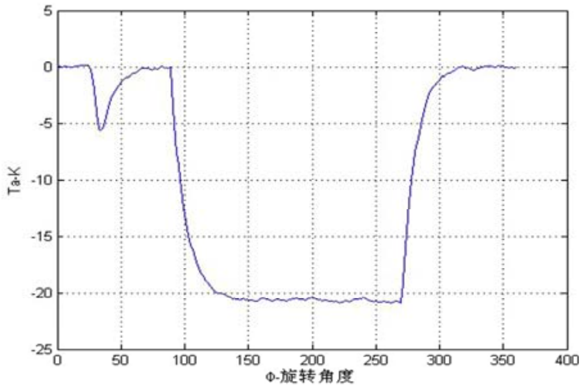

Fig. 4. The waveform of parameter at rotation speed 70 rad/s.

The figure above indicates the rocket projectile flies at a certain height and parallels to the horizontal X-axis as a rotating flight, the top of the rocket is equipped with antithetic formula millimeter wave radiometer, antenna beam first scans the ground, antenna receives radiation temperature on the ground, when the wave beam of radiometer scans the metal target edge, radiometer antenna receives a radiation temperature of the metal object, the reason for the bell shaped pulse signal shown in Fig. 3 is a temperature difference between the ground and the metal. After radiometer scans ground, the antenna receives the signal from scanning sky. The waveform with a rotation angle from 90° to 270° is formed when there is no metal target except the surface. This waveform is detection waveform used to depict radiometer rotates a circle, because it is antithesis radiometer and its direction has a normal angle of 30° with the ground, the ratio of radiation reaching ground to reaching sky is 1:2.

From the two figures above, the bell pulse outputted by the radiometer can be seen, besides, the pulse width, the maximum and minimum slope, the symmetry and height of the waveform can also be obtained, moreover, the threshold can be derived so as to calculate the geometric dimensioning of the target, and get the rendezvous information of target and detection system.

In the case of various parameters and undistorted waveforms, the corresponding parameters range is arrived at according to the variable parameter in actual flight of rocket projectile:

a). G_0=32.041 dB, θ_{3dB}=7.5°, θ_F=30°, 7.9×3.65 m^2, the contrast of the target and background is 50 degree, sampling interval is 0.1875 ms, The effective range of rotation speed is from 30 rad/s to 70 rad/s. When the maximum of rotation speed is 70 rad/s, the waveform is showed in Fig. 4.

b). G_0=32.041 Db, θ_{3dB}=7.5° ,θ_F=30°, 7.9×3.65 m^2, the contrast of the target and background is 50°, the rotation speed is 40 rad/s , The effective range of sampling interval is between 0.1105 ms and 0.275 ms. When the value of sampling interval is 0.275 ms, it is showed in Fig. 5.

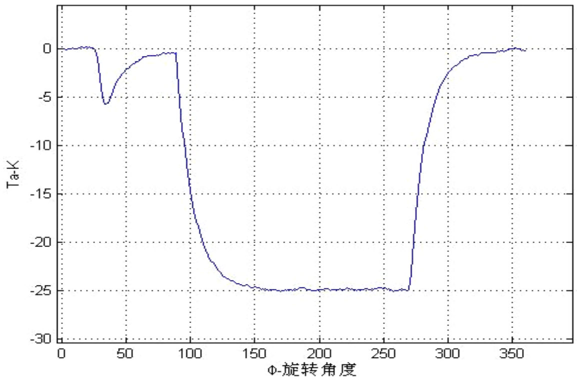

Fig. 5. The waveform of parameter at integration time 0.275 ms.

C). G_0=32.041 dB, θ_{3dB}=7.5°, θ_F=30°, 7.9×3.65 m^2, the contrast of the target and background is 50 °, the rotation speed is 40 rad/s, sampling interval is 0.1875 ms. The effective range of loitering height is from 17 m to 28 m, the target will not be accurately detected when the loitering height is more than the maximum, which may make the model system unstable, as shown in Fig. 6.

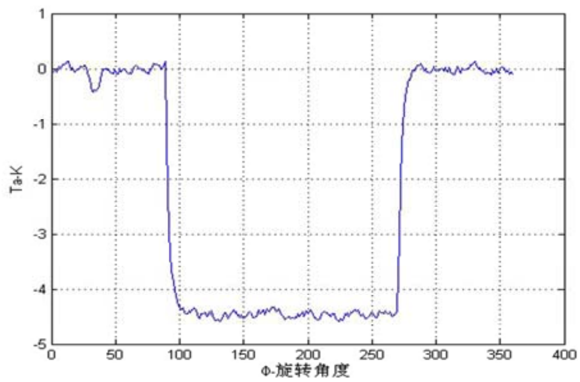

Fig. 6. The waveform of parameter at flat flight height 28 m.

When the other parameters are changed, the results of simulation were not obvious or they are not experimental. Therefore, after a large number of simulations and verifications, a conclusion can be drawn that the model is feasible when rocket projectile detects metal targets through millimeter wave radiometer.

5. Conclusions

According to the theory of millimeter wave radiometer, the rocket projectile, as a modern loaded weapons and ammunition detecting tool, has systematically achieved effective detection to the moving metal targets on the ground. By changing the rocket projectile parameters in flight and radiometer parameters, limits waveforms based on each parameter and effective detection range of parameters are obtained in the simulation results. Studies show that the establishment of this model has achieved the effective detection of moving targets on the ground and also provided significant practical applications to the identification of metal targets.

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