Analysis of Influencing Factors on the Capability of Ground Safety Remote Control Omnidirectional Antenna

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Abstract. Aiming at the capability of the ground-safe remote control omnidirectional antenna, the factors affecting its signal coverage are analyzed. The calculating method of antenna working boundary combining the width of the antenna beam is proposed. The determination of the effective working hours of the omnidirectional antenna is realized.

1. Introduction

Ground safety remote control is a device that implements safety control of rocket flight. It consists of a ground command generation system, a command sending system, and an onboard command receiving system. In order to ensure that the command issued by the commander in the event of abnormal flight can be accurately received by the rocket-borne receiver, the ground safety remote control equipment has always adopted the working mode of the first area omnidirectional antenna and the flight area directional antenna to implement the command transmission control. The omnidirectional antenna has large lobe width, wide coverage area, low gain, short operating distance, and the antenna does not need a guiding source; directional antennas have high gain, small lobe width, and long operating distance, and need to use a guiding source for antenna guidance. In the case of insufficient information redundancy in the initial flight segment and jitter of the passing signal, the stability of the guidance source will have a certain impact on the tracking stability of the directional antenna. Therefore, this full/directional antenna relay working mode is adopted. It can complement each other's advantages. It can ensure that the ground antenna is unstable in the initial flight, the flight height is low, and the control time is short. The omnidirectional antenna without a guide source can achieve wide-area coverage of the target without worrying about whether the antenna is can track the target, whether the target can reliably receive the command information and other problems. The safety control by the directional antenna relay at long distance of the target flight can be achieved, thus ensuring the reliability of the ground security control implementation during the whole flight.

From the above analysis, it can be seen that in the work of the ground safety remote control system, the main function of the omnidirectional antenna, that is, the maximum action time under the farthest range that it can track, is to ensure that the omnidirectional antenna is in the working period Reliability of implementation, the second is to accurately grasp the timing of the full/directional antenna conversion.

2. The working mechanism of remote control omnidirectional antenna

The ground-safe remote control omnidirectional antenna adopts the form of a conical logarithmic spiral antenna, which is a wide-beam directional antenna that radiates along the axis [1]. It is erected at a fixed angle and can capture the target without turning. The structure diagram is shown in Figure 1.
Figure 1. Schematic diagram of remote control omni-directional antenna structure

The polarization of the antenna is perpendicular to the axis of the cone, and its radiation characteristics are determined by the spiral with a circumference of $n\lambda$. When the spiral broadens quickly and the circumference of the cone becomes larger, the antenna pattern becomes wider. On the contrary, if the spiral line broadening speed is very slow, the cone circumference becomes smaller, and the antenna pattern becomes narrower. The remote control omni-directional antenna pattern calculated by HFSS simulation is shown in Figure 2 [2]. Its radiation pattern is similar to the heart shape and the beam is very wide. It can maintain good circular polarization characteristics in a wide frequency range, and the polarization direction is determined by the spiral direction.

Figure 2. Simulation pattern of remote control omnidirectional spiral antenna

It can be seen from Figure 2 that the effective radiation area of the omnidirectional antenna is basically in the area with a circumference of one wavelength. When the frequency changes, the effective radiation area moves along the axis, moves to the top of the cone when the frequency is high, and moves to the bottom of the cone when the frequency is low. Move [2], that is, in the direction of the antenna radiation angle $\theta=0^\circ$ (the angle between the antenna spiral radiator and the clockwise direction), the field strength is the largest, and when $\theta=180^\circ$, the field strength is the smallest, and the radiation propagation direction is mainly It is toward the front, and only a certain degree of diffraction exists in the rear direction [1], so that the omnidirectional antenna has broadband characteristics.

3. Analysis of Influencing Factors on the Ability of Remote Control Omnidirectional Antenna

From the above analysis of the basic working mechanism of the omnidirectional antenna and the simulation diagram of the antenna in Figure 2, the pattern coverage is shown as a spherical cylindrical space with a radius of $r$ and a height of $H = \frac{r}{\tan \theta}$, as shown in Figure 3.
It can be seen from Figure 3 that the size of the range of the omnidirectional antenna is affected by the radius $r$ and the antenna beam width. These two factors limit the working period of the omnidirectional antenna. Therefore, the analysis of the omnidirectional antenna's capability mainly refers to the determination of the effective working time of the omnidirectional antenna by analyzing the effective range and beam width of the omnidirectional antenna. Due to the high reliability requirements of ground safety remote control, the following are analyzed and calculated based on the accuracy of the omnidirectional antenna.

3.1. Analysis of influence factors of antenna beam width

According to the antenna pattern, the ground-safe remote-controlled omnidirectional antenna cannot achieve global control, but a certain deviation angle $\theta$ along the axial direction, the gain gradually attenuates. As shown in Figure 2, the size of the antenna radiation angle $\theta$ first affects the beam width, which determines the coverage of the omnidirectional antenna to the target. The target’s flying out of the beam range must be taken as the limiting condition of the omnidirectional antenna’s working ability to ensure the flying target is within the beam width that can implement omnidirectional antenna control. The second is to affect the antenna gain. If the half-power angle width is $90^\circ$ to estimate the level gain of the antenna coverage angle, the worst-case estimate of the antenna pattern gain is about 4dB (-2dB$\sim$2dB) lower than the $0^\circ$ direction. The radiation angle is different, the level gain is different, the action radius is different. Therefore, the antenna beam width will affect the effective radiated power and determine the coverage of the omnidirectional antenna to the target. The antenna beam width is determined by the antenna radiation angle.

3.2. Analysis of the influence factor of the operating distance

The working distance of the omnidirectional antenna determines how far the target can be tracked for the longest time it works. The maximum propagation distance formula of the effective radiation power of the transmitting antenna [1]:

$$EIRP - L_{SU} - L_{G} = S_{min}$$

Among them: $EIRP$ is the effective radiation power of the antenna, which is equal to the transmit power plus the antenna gain minus the feeder loss;

$$L_{SU} = 10\log\left(\frac{4\pi R}{\lambda}\right)^2 = 10\log\left(\frac{4\pi Rf}{c}\right)^2$$

is the path transmission loss, which is closely related to the range and transmission frequency; $L_{G}$ is a variety of interference losses for space propagation, including atmospheric absorption loss, multipath interference loss, etc.; $S_{min}$ is the receiver sensitivity.

If the transmission power of the ground omnidirectional antenna is $P_0$, the transmission frequency is $f = \frac{c}{\lambda}$, the transmission antenna gain is $G_t$, the transmission feeder loss is $L_f$, and the reception
antenna gain is $G$, then equation (1) is transformed into the following equation (2).

$$20\lg R = P_0 + G_t - L_r - L_{at} + G_r - S_{min} - 32.44 - 20\lg f$$  \hspace{1cm} (2)

(2) The formula is an ideal calculation formula for the antenna operating distance under the condition of known transmitting power and receiver sensitivity. From this formula, it can be seen that the antenna operating distance is not only closely related to the effective radiation power, the gain of the transceiver antenna and other factors, but also it is related to the working status of the receiver and the interference that may be generated during the transmission of various signals, and it needs to be considered in a comprehensive analysis combined with actual engineering applications.

3.2.1. Target flight characteristics influence

The impact of target flight characteristics mainly refers to the impact of target state changes on signal reception. The quality of signal reception will greatly affect the antenna range. The impact is manifested in three aspects, one is the tail flame attenuation, the second is the posture roll, and the third is the effect of high temperature.

(1) Rear-end tracking

In the process of tracking the target, the antenna usually traces to the tail of the target, causing signal attenuation caused by the tail flame. The attenuation is not only affected by the tracking angle, but also with the signal frequency, modulation system, fuel composition, and the angle at which the signal passes through the flame. Length is related, because it is difficult to give accurate data, in the estimation of the distance value, the maximum interference attenuation of the plume needs to be considered.

(2) The influence of the target flight attitude angle on the gain of the receiving antenna

During the flight of the target, its β angle is often in a state of change, as shown in Figure 4.

![Figure 4. Tracking angle β changes with time](image)

Figure 4. Tracking angle β changes with time

The change of β angle, especially in the case of attitude instability, will affect the signal receiving ability of the command receiver antenna on board. It is necessary to establish the relationship between the directional gain of the command receiver receiving antenna and the change of β angle as shown in Figure 7.

![Figure 5. The relationship between the directional pattern gain of the antenna receiver and the β angle](image)

Figure 5. The relationship between the directional pattern gain of the antenna receiver and the β angle

It can be seen from Fig. 5 that when the β angle changes frequently, the gain of the receiving antenna is constantly changing, and therefore, its operating distance is also changing dynamically. In
order to meet the reliable signal reception of the rocket-borne receiver, when estimating the operating range of the omnidirectional antenna, it is necessary to consider selecting the largest $\beta$ angle change and the smallest receiver sensitivity as the receiving antenna gain value, and redundancy is used to ensure the operating range reliability.

(3) Temperature influence

The sensitivity of the receiver's detection signal will be affected by internal noise and external noise. When certain anti-interference measures are taken to suppress and eliminate external interference, the impact of internal noise on receiver performance will be greater than external noise. A physical quantity that measures the internal noise level of the receiver is the receiver noise figure [3], and the relational expression between the noise figure $N_f$ and the receiver sensitivity $S_{min}$ is shown in equation (3).

$$S_{min} = K T B N_f (SNR)$$

In the formula, $K$ represents Boltzmann's constant, $T$ represents the absolute temperature of the signal source (standard noise temperature $T$ is 290K), $B$ represents the signal matching bandwidth, signal-to-noise ratio, and represents the system noise floor.

It can be seen from the formula that if the signal matching bandwidth, noise figure, and threshold carrier-to-noise ratio are given, the receiver sensitivity is related to the thermal noise power at the current temperature. When the ambient temperature changes significantly, the standard temperature $T$ is used to test the applied wave The Zmann constant $K$ will also drift, and the thermal noise power is no longer a constant [4]. At the same time, the increase in noise temperature will undoubtedly lead to an increase in the noise floor of the receiver, thereby reducing the sensitivity of the receiver and causing a change in the operating range. For this reason, it is necessary to consider the impact of changes in ambient temperature caused by high-speed movement and high-temperature thrust on the sensitivity of the receiver during the flight of the target.

3.2.2. Antenna polarization mode influence

When the electromagnetic wave polarization direction of the transmitting antenna is inconsistent with the polarization direction of the receiving antenna, the received signal will become smaller, that is, polarization loss will occur. The polarization state is determined by the axial ratio and the inclination angle [5], and the elliptical polarization efficiency formula [5] is shown in equation (4):

$$\eta_p = \left| \hat{e}_t \cdot \hat{e}_r \right|^2 = \frac{(r_t r_r + 1)^2 \cos^2 \Delta \tau + (r_t + r_r)^2 \sin^2 \Delta \tau}{(r_t^2 + 1)(r_r^2 + 1)}$$

Among them: the value range of polarization efficiency $\eta_p$ is $0 \sim 1$, $\eta_p = 1$ polarization matching; $\eta_p = 0$ polarization orthogonal [5]; $\hat{e}_t$ and $\hat{e}_r$ represent the unit vector of the electric field of the incoming wave (from the transmitting antenna) and the receiving antenna, respectively; $r_t$ and $r_r$ are the axial ratios of the transmitting antenna and the receiving antenna, respectively; $\tau$ is the angle between the long axis of the polarization ellipse and the x-axis parallel to the ground; $\Delta \tau = |\tau_t - \tau_r|$ is the difference in inclination of the two polarization ellipses.

The ground remote control omnidirectional antenna adopts circular polarization, the axis ratio is $r_t = r_r = 1$, and the polarization efficiency is changed from formula (4) to formula (5):

$$\eta_p = \cos^2 \Delta \tau + \sin^2 \Delta \tau = 1$$

That is, if the transceiver antenna is a standard circular polarization form, the incoming waves can be received by the circular polarization antenna, but it is usually difficult to achieve the standard circular polarization. In engineering applications, the antenna is basically calculated according to the
quasi-circular polarization. Let the axial ratio of the two quasi-circular polarizations, \( r_t = 1 + \Delta_t \)
\( r_r = 1 + \Delta_r \), then the polarization efficiency changes from formula (4) to formula (6) [1]

\[
\eta_p = 1 - \left( \frac{\Delta_t + \Delta_r}{2} \right)^2 + \Delta_t \Delta_r \cos^2 \Delta \tau
\]

When the inclination angle difference is \( \Delta \tau = 0 \), the polarization efficiency is the largest; when the inclination angle difference is \( \Delta \tau = \pm \frac{\pi}{2} \), the polarization efficiency is the smallest. It can be seen that the maximum received power received by the receiving antenna will change due to the angle change between the polarized antenna and the polarization vector of the electromagnetic wave. For this reason, when estimating the operating range of an omnidirectional antenna with guaranteed accuracy, it is necessary to estimate the antenna polarization loss caused by the target attitude change.

3.3. Influence of omnidirectional antenna installation position

In order to achieve reliable tracking of the target and try to avoid rear-end tracking affecting signal reception, ground remote control equipment is usually placed in a lateral position on the track, with its antenna facing the direction of the launching station. The positional relationship between the device antenna and the launching station in the launching coordinate system O-XYZ is shown in Figure 6.

![Figure 6. Schematic diagram of the relative position of the remote control equipment deployment station and the shooting direction](image)

It can be seen from Figure 6 that this mode of station deployment can effectively achieve effective coverage of the omnidirectional antenna range in all directions in the south, east, north, and west. The electrical axis of the antenna is aligned with the direction of the launching station, and is at a certain angle with the launching station according to a certain installation position, as shown in Figure 7.

![Figure 7. Schematic diagram of the relative position of the device antenna and the target](image)
Suppose that the installation angle of the remote control antenna is $\alpha$, and the angle between the height difference between the antenna and the transmitting station is $\psi$. Obviously, if and only if the effective coverage angle $\theta$ of the antenna is equal to the sum of the angle between the installation angle and the height difference $\theta = \alpha + \psi$, the maximum operating distance of the omnidirectional antenna can be exerted. However, it can also be seen that when the antenna angle $\alpha$ is appropriately raised, the working period of the omnidirectional antenna will be extended. Therefore, the antenna installation angle will affect the coverage period of the omnidirectional antenna.

4. Calculation and analysis of omnidirectional antenna capability

4.1. Accuracy-guaranteed range calculation

From the above analysis of the influence factors of the operating distance, it can be seen that the distance of the signal propagation in space is closely related to the attitude of the flying target. When estimating the distance, the polarization mode of the antenna, the influence of the $\beta$ angle change on the receiving antenna, and the effect of the tail flame on the receiving antenna should be considered. The influence of signal attenuation and temperature on receiver sensitivity are comprehensively considered, and the distance calculation formula is shown in formula (7).

$$20 \log R = P_0 + G_t - L_T - L_{\alpha, \psi, w} + G_r - S_{\min} - 32.44 - 20 \log f$$

(7)

The value requirements are as follows:

- Antenna polarization loss value $L_T = 2 \text{dB} - 4 \text{dB}$;
- The value of tail flame attenuation loss $L_T = 10 \text{dB} - 16 \text{dB}$;
- Transmit antenna gain is taken according to the cylindrical coverage area of $\pm 90^\circ$, $G_t = 0 \text{dB} - 2 \text{dB}$;
- The gain of the receiving antenna is determined according to the $\beta$ angle $G_r = -4 \text{dB} - 8 \text{dB}$;
- Receiver sensitivity is based on the attenuation caused by temperature changes based on the normal temperature test value $S'_{\min}$, $S_{\min} = S'_{\min} + (1 \text{dB} - 2 \text{dB})$.

In practical engineering applications, if the effective radiation power is low and the receiving sensitivity is low, the distance is small; the effective radiation power is high and the receiving sensitivity is high, and the distance is long. The above parameter values are selected and calculated according to the maximum value, leaving at least 30dB margin, from the perspective of margin to ensure the accuracy of the operating distance, so as to ensure the reliability of the omnidirectional antenna.

4.2. Estimation of antenna capability based on beam width

The antenna beam width determines the coverage of the omnidirectional antenna to the target. In order to ensure the reliability of the antenna range, in actual engineering applications, the antenna coverage angle range is $\pm 60^\circ$, and it is necessary to ensure that the target flight does not exceed this area. Since the omnidirectional antenna cannot complete the angle judgment by itself, it is necessary to use the theoretical trajectory calculation method to estimate the omnidirectional antenna capacity based on the target flight trajectory. The basic idea is to judge whether the angle between the connection between the target and the antenna site and the antenna's electrical axis exceeds the effective radiation angle $\theta$. Take the antenna site as the origin to establish a rectangular coordinate system as shown in Figure 8.
Figure 8. Schematic diagram of the connection between the target and the omni-directional antenna site and the position of the full-line antenna

Point m is the target at any point in the coverage area of the omnidirectional antenna, and \( \omega \) is the angle between the line between the target and the antenna site and the electrical axis of the antenna. By knowing the theoretical ballistic point track coordinates \((x, y, z)\) in the launching inertial system, the point m can be obtained by the coordinate conversion and translation to obtain the space target position value \((x', y', z')\) based on the equipment site. The calculation process of the angle \( \omega \) between the target space position and the omnidirectional antenna is as follows:

1. Calculate the distance from the target to the site:
   \[
   r_{om} = \sqrt{x_c^2 + y_c^2 + z_c^2}
   \]  
   (8)

2. Assuming that \( \vec{o_d} = r_{om} \), \( \vec{od} \) are the electrical axis directions of the omnidirectional antenna, the angle values in polar coordinates are fixed values (A, E), where E=0, convert the polar coordinates to the rectangular coordinate value \((x_d, y_d, z_d)\) when the distance is equal to \( r_{om} \), As in formula (9),
   \[
   \begin{bmatrix}
   x_d \\
   y_d \\
   z_d \\
   \end{bmatrix}
   =
   \begin{bmatrix}
   r_{od} \cos A \cos \theta \\
   r_{od} \sin \theta \\
   r_{od} \sin A \cos \theta \\
   \end{bmatrix}
   \]  
   (9)

3. Calculate the distance \( r_{dm} \)
   \[
   r_{dm} = \sqrt{(x_c - x_d)^2 + (y_c - y_d)^2 + (z_c - z_d)^2}
   \]  
   (10)

4. Calculate the included angle \( \omega \)
   \[
   \cos \omega = \frac{r_{od}^2 + r_{om}^2 - r_{dm}^2}{2 r_{od} r_{om}^2} = \frac{2 r_{om}^2 - r_{dm}^2}{2 r_{om}^2}
   \]  
   (11)

When \( \omega \geq \theta \) is considered that the target is beyond the coverage area of the omnidirectional antenna, the target position corresponding to \( \omega = \theta \) is the moment when the omnidirectional antenna exceeds the \( \pm \theta \) boundary position (any direction). At this time, combined with the accuracy-preserving range, take the effective radiation angle and the accuracy The minimum time value \( \min\{t(R_{MAX}), t(\omega)\} \) corresponding to the operating distance is the maximum boundary time of the omnidirectional antenna.
The coverage area calculated according to this formula, as long as the omnidirectional antenna guarantees the accuracy range and effective radiation angle, no matter what abnormal flight situation occurs, the omnidirectional antenna can achieve effective coverage of the target, that is, it can ensure the target’s reliable reception of ground launch control commands greatly reduces the unpredictable damage consequences caused by missing commands and failing to terminate the flight of the faulty rocket in time.

4.3. **Analysis of effective working period of omnidirectional antenna**

Three factors are considered when analyzing the working capability of an omnidirectional antenna:

1. Evaluate the capability of the omnidirectional antenna. The key to analyzing the working capability of an omnidirectional antenna is to ensure that the flying target is within a certain beam width while ensuring the accuracy of the range. The working arc of the omnidirectional antenna is less than or equal to the distance of the omnidirectional antenna to ensure accuracy, and the target is within ±θ of the omnidirectional antenna electric axis radiation angle direction.

2. Analyze the antenna performance and establish the corresponding relationship between antenna radiation characteristics and operating distance. As shown in Figure 9.

![Figure 9](image.png)

Figure 9. Level values of special points in the omnidirectional antenna control area

Figure 9 shows the estimated levels and distances of special points in the control area within a plane of the omnidirectional antenna. Outside the brackets in the figure is the estimated level of the coverage angle, and inside the brackets is the estimated range of action.

3. Combining mission requirements, give full play to the advantages of omnidirectional antennas.

For example, when installing a remote control omnidirectional antenna, install it according to the effective radiation angle; on the other hand, when performing some special tasks, you can combine the requirements of the initial arc of the security control and the requirements of the subsequent tasks to appropriately raise the installation angle. This not only ensures the coverage of the initial security control by the omnidirectional antenna, but also satisfies the saturated working period of the omnidirectional antenna, so that the efficiency of the omnidirectional antenna can be maximized.

5. **Conclusion**

The ground safety remote control omnidirectional antenna is an important means to implement the first zone flight safety control. However, there has always been a problem of lack of quantitative analysis and fuzzy calculation of its maximum working boundary, which has affected the performance of the omnidirectional antenna. It may even be due to improper application of the omnidirectional antenna’s working timing. For example, if you convert to a directional antenna prematurely when you can continue to work with the omnidirectional antenna, the reliability of command execution is reduced. Or if the omnidirectional antenna capacity range is exceeded, the omnidirectional/directional antenna state conversion is not implemented, affecting command execution, etc.. These problems will have a very large impact on the implementation of ground security control, and even irreparable consequences. Therefore, the accurate analysis of the omnidirectional antenna capability and the
The determination of the working boundary are important guarantees for ensuring the reliability of the command execution of the first flight segment and the reasonable completion of the antenna working mode conversion. Mastering the working performance of the antenna can help engineers and technicians to apply the omnidirectional antenna proficiently in the execution of different tasks. While giving full play to the advantages of the omnidirectional antenna's wide airspace coverage and ensuring the timing of conversion, it can effectively enhance the target under abnormal flight conditions in the first area. The reliable improvement in the ground security control ability is achieved.

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