Research on Simulation and Test of Antenna Isolation of Airplane and Spacecraft Platform

Wang Yuan\textsuperscript{1,*}, Kong Rong\textsuperscript{1,b}, Tan Wei\textsuperscript{1,c}, Cui Lidong\textsuperscript{1,d}
\textsuperscript{1}BeiJing Institute of Tracking and Telecommunication Technology, BeiJing, China
\textsuperscript{*}email: wangyuan@bittt.cn, \textsuperscript{b}email: kongrong@bittt.cn, \textsuperscript{c}email: tanwei@bittt.cn
\textsuperscript{d}email: cuilidong@bittt.cn

Abstract. In order to discover in time the potential interference coupling relationship caused by the installation of multiple types of frequency-using equipment and antennas on an aircraft or spacecraft platform, and to improve the rationality and compatibility of the antenna layout. The antenna isolation must be simulated at the beginning of the aircraft or spacecraft platform design, and the antenna isolation must be tested before the antenna is installed. In this article, the simulation and test results of the real case show that the model construction error during simulation, the actual spatial attenuation, the actual diffraction attenuation, the actual occlusion factor and the test error during the test process have formed the preliminary error relationship between simulation results and test results.

1. Introduction
The functional diversity of spacecraft platforms such as satellites and space stations, and aircraft platforms such as airplanes have led to more and more complex frequency equipment installed on such platforms. The number of antennas installed on the limited platform space is increasing, the signal radiation power of the transmitting device is large, the receiving device is highly sensitive, the system working frequency is wide. The mutual coupling relationship between the devices is very complicated, and some platforms have serious frequency overlap. The electromagnetic compatibility of frequency-using equipment on these platforms has become a key factor restricting the successful development of aerospace or aircraft. Improving the isolation between the antennas of these frequency-using equipment is an important technical means to solve the electromagnetic compatibility between equipment on such platforms. After the antenna layout is completed, further antenna isolation tests are carried out to verify the correctness of the antenna isolation simulation calculations. After the equipment and antenna are installed on the platform, the installation position of the antenna and equipment cannot be changed arbitrarily. Therefore, it is necessary to simulate the antenna isolation of the equipment installed on the platform at the early stage of system design to guide the layout of the platform antenna. After the antenna layout is completed, further antenna isolation testing can be carried out to verify the correctness of the antenna isolation simulation calculation [1]. Its main purpose is to discover the existence of potential interference coupling relationship, and provide test data and design basis for the further optimization of the layout of the whole machine antenna and the electromagnetic compatibility lockout control strategy of the platform.
2. Antenna isolation calculation and simulation

Antenna isolation $L$ refers to the ratio of the transmit power $P_t$ at the transmitting antenna end to the power $P_r$ received by the receiver antenna, where $P_r$ is the power value that $P_t$ reaches the receiver after various attenuations. The isolation of the antenna determines the amount of electromagnetic energy that the antennas couple with each other, and it determines the electromagnetic compatibility between the transceiver equipment.

2.1. Antenna isolation calculation

The antenna isolation calculation mainly distinguishes the difference between the far-field and near-field states, and on this basis, it is necessary to further consider the situation of obstacles between the transmitting and receiving antennas.

2.1.1. Antenna isolation in the far field without obstacles.

The coupling between the far-field antennas is mainly produced by the radiation field [2]. Suppose the transmitting power of the transmitting antenna is $P_t$, the gain is $G_t$, the receiving power of the receiving antenna is $P_r$, and the gain is $G_r$. The distance between the receiving antenna and the transmitting antenna is $r$, and the size of the transmitting and receiving antenna is small compared with $r$. The transmitting and receiving antenna can be regarded as a point source with a certain directivity, and the electromagnetic wave emitted by the transmitting antenna can be approximated as a spherical surface wave, and can be regarded as a plane wave at the receiving antenna [3], the antenna isolation $L$ can be expressed as:

$$
L = 20\lg\left(\frac{4\pi D}{\lambda}\right) + G_t - G_r + L_p
$$

Among them, $L_d = 20\lg\left(\frac{4\pi D}{\lambda}\right)$ is the spatial isolation under the direct view of the transmitting and receiving antennas, and $L_d$ is determined by factors such as the distance $D$ between the transmitting and receiving antennas and the frequency $\lambda$.

$G_t$ is the antenna gain of the transmitting antenna in the receiving direction.

$G_r$ is the antenna gain of the receiving antenna on the platform in the transmitting direction.

$L_p$ is the polarization mismatch loss. In engineering, the mismatch loss of circular polarization to vertical or horizontal polarization is about 3dB, and the mismatch loss between vertical polarization and horizontal polarization is 20 to 35 dB.

2.1.2. Antenna isolation under obstacles in the far field.

In the case of obstacles in the far field, the problem of signal diffraction in space needs to be considered. When there is diffraction, according to formula (1), the far-field antenna isolation can be obtained as follows:

$$
L_{\text{antenna}}(\text{dB}) = L_p + L_d - G_t - G_r
$$

Where $L_p$ is the polarization attenuation between the transmitting and receiving antennas.

$$
L_d = 20\lg\left(\frac{4\pi D}{\lambda}\right) + L_{\text{diffraction}} + SF_{\text{p}} - G_t - G_r
$$

and $L_d$ is determined by factors such as the distance $D$ between the transmitting and receiving antennas, diffraction attenuation, blocking attenuation, and frequency.

$G_t$ is the antenna gain of the transmitting antenna in the receiving direction.

$G_r$ is the antenna gain of the receiving antenna in the transmitting direction.

2.1.3. Antenna isolation in near field.

The mutual interference between the two antennas in the near-field state is not mainly generated by the radiation field, but by the near-area binding field or near-area induction field. Therefore, in the near field, the system composed of the two antennas to be analyzed is generally regarded as a two-port network [4]. The relationship between the current and voltage between the ports is expressed by the impedance matrix as follows:
\[
\begin{pmatrix}
V_1 \\
V_2
\end{pmatrix} =
\begin{pmatrix}
Z_{11} & Z_{12} \\
Z_{21} & Z_{22}
\end{pmatrix}
\begin{pmatrix}
I_1 \\
I_2
\end{pmatrix}
\]

Among them, \(Z_{12}\) and \(Z_{21}\) are mutual impedance. When the medium is isotropic, the network is reciprocal. If antenna 1 is used as a transmitting antenna and fed with voltage \(V_1\), antenna 2 is used as a receiving antenna, and a load impedance \(Z_2\) is connected, and its voltage is \(V_2\), the ratio of \(V_1\) to \(V_2\) can be easily obtained from the following impedance matrix:

\[
\frac{V_1}{V_2} = \frac{Z_{11}(Z_2 - Z_{22}) + Z_{12}Z_{21}}{Z_2Z_{21}}
\]

According to the definition of antenna isolation, the formula is as follows:

\[
L = \frac{P_r}{P_t} = \frac{|V_2|^2}{|V_1|^2} \left( \frac{R_1}{R_2} \right)
\]

\(R_1\) is the real part of the transmitting antenna input impedance \(Z_1\), and \(R_2\) is the real part of \(Z_2\). In actual engineering, the calculation of \(R_1\) and \(R_2\) is a difficult problem. Electromagnetic simulation software can be used to calculate the S parameter, and the near-field antenna isolation can be solved by the following formula:

\[
L(dB) = 10 \log \frac{P_r}{P_t} = 10 \log \left| \frac{|S_{12}|^2}{1 - |S_{11}|^2} \right|
\]

2.2. Antenna isolation simulation

2.2.1. Simulation method. Antenna isolation simulation is mainly done using HFSS electromagnetic simulation software. The method and steps of far-field antenna isolation simulation are as follows:

- Simulate the geometric shape of the aircraft or spacecraft platform, and appropriately simplify it, so that it is convenient to use the classic problem solution in GTD to calculate the space isolation \(L_d\);
- Use HFSS software to simulate the radiation direction characteristics of the transceiver antenna;
- Determine the short-range line between the transmitting and receiving antennas, and calculate the transmitting and receiving angles of the transmitting and receiving antennas to obtain the transmitting power gain and the receiving power gain;
- Calculate the isolation of the far-field antenna.

The simulation method and steps of near-field antenna isolation are as follows:

- Construct the geometric model of each element of the aircraft or spacecraft platform through HFSS software.
- Set the electromagnetic parameters of each relevant part of the electromagnetic environment on the basis of the geometric model, then set the radiation source and boundary conditions in the Setup Boundary/source module. The Setup Solution module provides some limited conditions for selecting and solving electromagnetic problems, such as frequency, fixed point frequency, sweep frequency, meshing method, and convergence characteristics. And then carry out electromagnetic calculations through the Solve module.
- After completing the electromagnetic calculation, extract the S parameters (including \(S_{12}\) and \(S_{11}\)), and calculate the near-field antenna isolation by formula (6).

2.2.2. Simulation example. Take the simulation of the near-field antenna isolation between an ultrashort wave radio antenna (transmitting) and a GNSS antenna (receiving) on an aircraft platform as an example.

First, use the Draw module to establish a simplified geometric model of the electromagnetic simulation of the aircraft, and then use the Setup Materials module to set up the materials of the antenna and each part of the aircraft. After completing the above work, establish the transmitting and
receiving antenna model and the pattern model. The simulation results of the aircraft platform model, the transmitting antenna model and the direction of the installation direction are shown in Figure 1. The GNSS receiving antenna model and the directional pattern simulation results of the installation direction are shown in Figure 2.

![Figure 1. Transmitting antenna model and pattern simulation in the installation direction](image)

![Figure 2. GNSS antenna model and pattern simulation in the installation direction](image)

Use the Boundary/source module to set the transmitting antenna source and radiation boundary conditions, and use the Setup Solution module to set the center frequency and grid division method. After these parameters are set, the solution can be started. After the calculation is completed, the $S_{11}$ and $S_{12}$ parameter values are obtained according to formula (6), and the antenna isolation in the near-field area can be calculated. By changing the installation position of the GNSS receiving antenna, the simulation calculation results are shown in Table 1.

### Table 1. The simulation results of the near-field antenna isolation between the radio antenna and the GNSS antenna

| Antenna pair                  | Frequency (MHz) | Isolation (dB) |
|------------------------------|-----------------|----------------|
| Ultrashort wave radio        | 1575.42         | 54.18          |
| transmitting antenna         |                 |                |
| GNSS receiving antenna (position 1) | 1575.42 | 103.9          |
| GNSS receiving antenna (position 2) | 1575.42 | 81.24          |

#### 3. Antenna isolation test

The antenna isolation test can be equivalent to measuring the power transmission coefficient of a two-port network[5], that is, the antenna isolation is equal to the ratio of the input power of the transmitting antenna port to the output power of the receiving antenna port. In the actual test process, we only need to measure the input power $P_{in}$ of the transmitting antenna port and the output power $P_{out}$ of the receiving antenna port respectively. The test equipment connection is shown in Figure 3.
After the test, calculate the isolation between the transmitting and receiving antennas according to the following formula:

$$L = 10 \log \left( \frac{P_{in}}{P_{out}} \right)$$ (7)

According to the previous simulation example, the antenna isolation test and calculation were carried out on the ultrashort wave radio antenna (transmitting) on an aircraft platform and the GNSS antennas (receiving) installed in three different positions. The transmitting frequency range is 1520–1610MHz, and the antenna isolation test results after installing the GNSS antenna at three positions are shown in Figure 4, Figure 5 and Figure 6.

Figure 3. Connection diagram for antenna isolation test

Figure 4. Antenna isolation test results when the GNSS antenna is in position 1

Figure 5. Antenna isolation test results when the GNSS antenna is in position 2

Figure 6. Antenna isolation test results when the GNSS antenna is in position 3
The test results show that the antenna isolation between the ultrashort wave radio transmitting antenna and the GNSS antenna installed in three different positions is 59dB, 108dB and 86dB, respectively, the frequency is 1575.42MHz. The difference between actual test and simulation results is no more than 5dB. The main influencing factors include model error, actual spatial attenuation, actual diffraction attenuation, occlusion, and test error.

4. Conclusion
Antenna isolation simulation and testing is an indispensable and important stage after the aircraft or spacecraft platform is equipped with a variety of frequency-use mission equipment. The simulation calculation of the antenna isolation at the beginning of the platform design provides an important technical basis for the antenna layout. Testing the antenna isolation before antenna installation can further verify the simulation results and improve the accuracy of the platform's electromagnetic compatibility design and antenna layout. It can provide test data for safety analysis and antenna optimization layout of the installed equipment. This paper analyzes the simulation and test results of the examples and shows that the model construction errors during the simulation, the actual spatial attenuation, the actual diffraction attenuation, the actual occlusion factors and the test errors during the test process, etc., have caused the preliminary error relationship between the simulation results and the test results. It is no more than 5dB.

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