Simulation analysis of passive intermodulation mechanism of transceiver link

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Abstract—The electromagnetic environment of modern battlefield is complex and the interference intensity is large. Under the influence of high field electromagnetic interference, airborne RF equipment becomes the short board of electromagnetic environment adaptability of aircraft. Because of the wide application of military aircraft platform, the external climate and electromagnetic environment are very complex. At the same time, the interior space of military aircraft is narrow and there are many high-power frequency equipment, which lead to a very complex electromagnetic environment inside the aircraft. Under the irradiation of high-power electromagnetic field, passive intermodulation products will be produced in the receiving antenna, transmission line, connector, filter and even some non-metallic conductive materials and aircraft skin under certain conditions. The passive intermodulation products will cause great interference to the airborne high sensitivity receiving equipment, and even burn the receiving equipment in extreme conditions. Therefore, the research on passive intermodulation products of airborne equipment is very urgent.

1. INTRODUCTION

When multiple high-power signals pass through a linear circuit, there will be nonlinear effects due to the uneven contact surface, different stress, different temperature and oxide film on the surface. This phenomenon is called passive intermodulation (PIM), which is caused by the nonlinear response of traditional linear circuits[1]. Passive inter-modulation will produce obvious interference to the system under the condition of high power irradiation, but due to the lack of relevant test methods and standards, such interference has been ignored in the development of weapons and equipment for a long time. Therefore, the mechanism of passive intermodulation interference must be studied and analyzed, and then effective test and improvement methods to solve the problem of passive intermodulation[2].

This paper will analyze the PIM generation mechanism of airborne RF system from internal and external factors[3]. For the study of internal factors, we will use COMSOL multi physical field simulation to analyze the PIM generation sources under multiple conditions. For the study of external factors, we will use CADFEKO suite to analyze the coupling channel of PIM.

2. THEORETICAL ANALYSIS

2.1 Analysis of Internal Factors

The formation mechanism of PIM interference can be divided into contact nonlinearity and material nonlinearity[4]. Material nonlinearity has been avoided in the design of RF devices. Therefore, this
paper mainly analyzes the micro-mechanism of PIM on the helicopter platform in terms of contact nonlinearity.

In this part, we mainly study the micro contact mechanism of PIM through COMSOL multi physical field simulation component. Through the multi physical field coupling simulation of different kinds of device contact surfaces, and comparing the V-A characteristics of contact surfaces in different environments, the PIM sources on the military aircraft platform are analyzed. This contact effect may exist in the connection of antenna, filter, adapter, connector and RF cable. By setting the thermal field and electromagnetic field in the COMSOL package, we can simulate the possible situation of the contact surface.

The contact points are MM contact, MIM contact and gap contact, as shown in Figure 1 (a). In order to simulate the working condition of micro contact surface, we have built micro equivalent model in COMSOL multi physical field simulation software. The contact surface model is shown in Figure 1 (b).

![Figure 1. Contact surface equivalent model and COMSOL equivalent model](image)

The contact mechanism mainly appears in the transmission link. In the contact link, there is a high-power two-tone signal passing through the same contact surface. Due to the non-linear effect of the contact surface, the phenomenon of mutual modulation of the two-tone signal is easy to occur, thus generating a new frequency interference signal.

In order to get a more extensive and close to the actual contact surface model, we use MATLAB to generate Gaussian random surface, as shown in Figure 2. The Gaussian surface generated in this paper is mainly based on the AR model two-dimensional digital filtering technology. This method can simulate the rough surface that meets the requirements by programming. The roughness of the surface is mainly determined by the results of autocorrelation function.

![Figure 2. Gauss rough surface](image)

2.2 Analysis of External Factors

With the rapid development of modern communication system, higher requirements are put forward for the broadband miniaturized antenna system of shortwave and ultra-short wave. The antenna should not only meet the VSWR, gain and efficiency in the working frequency band, but also meet the limitations of antenna structure and size. In addition, with the continuous development of information and electronic technology, more and more electronic devices and their supporting antennas need to focus on
a limited range of platforms. In this case, the coupling interference of PIMP becomes more serious due to the extension of receiving band and transmitting band and the high integration of equipment.

According to the actual situation, not only the performance of the antenna is required to meet the requirements, but also the weight of the antenna is required to be light, the size is small, the profile is low, and the structure of the antenna will not increase aerodynamic resistance. Based on the above considerations, the knife antenna with streamline design, high integration and wide frequency band has been widely used in both civil and military fields. So the simulation work of this paper takes the knife antenna as an example.

The external factors mainly analyze the interference caused by the coupling effect with the high sensitivity receiver. Taking the L-band antenna on the military aircraft platform as an example, the L-band antenna is modeled in the form of knife antenna, and the antenna model is shown in Figure 3. The coupling paths of intermodulation products between different L-band antennas are analyzed by placing antennas at different positions on the aircraft model. The antenna arrangement is shown in Figure 4.

3. SIMULATION ANALYSIS
Based on the above theoretical analysis, the internal factors and external factors are simulated, and the simulation results are analyzed.

3.1 Simulation Results and Analysis of Internal Factors
The internal factors mainly simulate the contact effect and thermal effect of rough contact surface. The simulation results are as follows:
Through the simulation results, it can be seen that when the external temperature changes, there will be uneven potential distribution on the contact surface. When use Gaussian random surface for simulation analysis, it can be seen that this phenomenon is more obvious. In practical application, the contact surface will become rough due to the humid air corrosion or oxidation corrosion, which makes the potential generated on the contact surface nonlinear distribution. This will lead to non-linear effect of RF signal through the contact surface, which will generate new frequency interference signal and cause interference to the communication quality of the communication system.

3.2 Simulation Results and Analysis of External Factors

In the simulation of PIM transmission coupling, we equivalent the transmission of L-band transmitting antenna to the receiving antenna as a high-power plane wave incident on the L-band receiving antenna in space, and then analyze such interference through the induced current generated on the antenna surface. This kind of PIM interference is the main source of PIM products of receiving link[5-6].

The simulation of external factors is mainly carried out from two aspects: one is to simulate the influence of the distance between the transmit and receive antennas on the interference intensity; the other is to simulate the influence of the relative position of the transmit and receive antennas on the interference intensity.

(1) Simulation results of different distance between transmitting antenna and receiving antenna

When the transmitting power is the same, different distances between the transmitting antenna and the receiving antenna are set respectively. By observing the nonlinear current on the surface of the receiving antenna at different distances, the simulation results of different distances between the transmitting antenna and the receiving antenna are analyzed. The distance setting between the transmitting antenna and the receiving antenna is shown in Table 1.

| Distance(m) | $d_1$ | $d_2$ | $d_3$ |
|------------|-------|-------|-------|
| 1          | 1.5   | 2     |       |

TABLE I. DISTANCE BETWEEN TRANSMITTING ANTENNA AND RECEIVING ANTENNA
The simulation results are shown in Figure 7. It can be seen from the simulation results that the coupling current decreases with the increase of the distance between the receiving antenna and the transmitting antenna, which is caused by the attenuation effect of free space electromagnetic wave.

Figure 7. Simulation results of different transmitting antenna positions

(2) Simulation results of different position of receiving antenna

In this part we keep the positions of the two transmitting antennas unchanged, set the distance between the receiving antenna and the center point of the two transmitting antennas as 2m, keep the distance unchanged, move the position of the receiving antenna, and the moving angle of the receiving antenna is shown in Table 2. The nonlinear current excited at the receiving antenna is simulated in different directions, and the position of the receiving antenna is shown in Figure 8.

| Angle(°) | 30 | 60 | 90 | 120 | 150 |
|---------|----|----|----|-----|-----|

Figure 8. Position of receiving antenna in different directions
The simulation results are shown in Figure 9.

(a) $\theta = 30^\circ$  
(b) $\theta = 60^\circ$  
(c) $\theta = 90^\circ$  
(d) $\theta = 120^\circ$  
(e) $\theta = 150^\circ$

Figure 9. Surface current distribution of receiving antenna

It can be seen from the simulation results that the nonlinear current at the receiving antenna does not change obviously with the change of angle. This is because the distance between the two transmitting antennas is relatively close, which can be regarded as the same radiation source approximately. However, in either case, the local nonlinear current coupled to the receiver is more than 15dBA/m. The generated PIM interference signal will affect the receiving performance of the receiver. It can be seen that the nonlinear current generated by the coupling of this kind of near-field environment will also cause the PIM interference problem.

4. CONCLUSION

In this paper, the source of PIM interference in the transceiver link under the working condition is clarified through the multi physical field simulation of the connector contact surface of airborne RF equipment. Through the simulation of the surface current at the receiving antenna in the receiving link, it is verified that there is a nonlinear current generated by the excitation of the field source in the receiving link, which leads to the PIMP at the receiving end. Because the frequency of the third-order PIMP is very close to the frequency of the transmitted signal, it will be coupled into the receiver around the filter device at the back end in the working state of the communication system, which will affect the performance of the receiver.
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