Coupling Effect Analysis of Airborne Cable under High Intensity Radiation Field Environment

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Abstract. With the improvement of equipment informatization, the importance of electromagnetic compatibility and the adaptability of complex electromagnetic environment has become increasingly prominent, and the influence of high intensity radiation fields (HIRF) on aircraft electronic equipment has become more and more significant, which has seriously threatened flight safety. In order to examine the coupling characteristics of airborne cables under HIRF irradiation, this paper used FEKO electromagnetic simulation software for analysis and study. The influence of different radiation fields, cable types, installed positions and gap structure on the simulation results was analyzed. And coupling patterns of airborne cables in the HIRF environment were obtained. The conclusions obtained in this paper have a definite guiding significance of the research on airborne cable protection for HIRF.

1. Introduction

In terms of electromagnetic characteristics, HIRF is usually marked by instantaneous, ultra-high strength and wide band, and has amplitude-frequency characteristics completely different from conventional electromagnetic interference signals[1,2]. The HIRF environment of an aircraft mainly relates to the high-intensity radiation field formed by the coupling of signals from radar, radio, television and other ground, surface and air of transmitters through aircraft materials, lap joints, gaps and openings. If the electronic and electrical systems of the aircraft are affected by HIRF, the cables will generate a high induced current or voltage[3]. When the induced current or voltage exceeds a certain threshold, the system will be concerned.

In order to adapt to the increasingly complex battlefield electromagnetic environment, the external HIRF environment penetrates the aircraft and affects the onboard cables and equipment[4,5]. On the basis of ensuring the flight safety of the aircraft platform, HIRF protection design and verification should be carried out to better play the performance of airborne electronic equipment[6].

2. Simulation software

The core algorithm of FEKO is time domain algorithm, which also integrates a variety of acceleration algorithms including fast multipole and multi-layer fast multipole, so that the calculation accuracy and efficiency are guaranteed[7,8]. The calculation principle is as follows: for the metal conductor, the surface current distribution on the conductor surface is first calculated[9]. For the dielectric body, the equivalent surface current and the equivalent surface flux on the surface of the dielectric body is first calculated. The surface current, you can calculate the near-field, far-field, RCS, directional diagram, or antenna input impedance.
3. Establish the simulation model
The establishment of the basic helicopter model is presented in figure 1 and figure 2. An airborne single-core cable with a length of 3m and a radius of 0.003m is placed horizontally at a distance of 0.1m from the ground. The cable is connected to the 50 ohm load resistance at each end and then ground. The outer skin of the aircraft body is made of metal, which can be assumed to be a good conductor of the simulation. Since the aircraft is far away from the radiation source, the electromagnetic wave irradiated to the aircraft model can be viewed as a plane wave. Therefore, the excitation source is set as a uniform plane wave with an electric field intensity of 200V/m and an incident direction of -X axis. The polarization mode of the electric field is vertical polarization.

The simulation model, cable wiring path and cable lapping structure is shown in figure 1:

![Figure 1. Model of body and cable path.](image1)

![Figure 2. Schematic diagram of cable wiring model.](image2)

In the frequency band of 10KHz~400MHz, it is mainly embodied as the induced current at the cable end. The main influence in the 100MHz~18GHz frequency band is the electric field at the position of the equipment. Therefore, the simulation modeling frequency is set to 10KHz~400MHz. At the same time, considering the model size and simulation efficiency, when the radiation frequency is in 10KHz~100MHz band, the moment method is employed for simulation calculation. In 100MHz~400MHz band, multi-layer fast multipole algorithm is used for simulation calculation. In FEKO software, POSTFEKO interface can be utilized to display the simulation results twice at the same time. Since the connection is a linear impedance of 50 ohms, the voltage and current at the same position of the same cable is linearly proportional, so only the calculation results of the induced current are given in this paper.

4. Results and analysis
In this paper, conduction coupling characteristics of aircraft internal cables within the frequency range of 10KHz~400MHz under HIRF irradiation are simulated. In order to simulate the influence of changed lines on the protection of HIRF, the following cables were simulated according to the possible cable forms and the setting conditions of simulation software. The wiring paths, line types and wiring topologies are set in the aircraft structure model to generate the required cable model. For airborne cables, the external electromagnetic wave incidence conditions, cable length, cable type and size, as well as the external structure of the airframe, have certain impact on their use.

4.1. The influence of the incident direction of the uniform plane wave on the coupling
Based on the basic simulation model, the effects of different incident directions of the electromagnetic field on cable coupling are calculated. When the incident direction is -X axis, +y axis and -y axis respectively, the induced current simulation results of the cable core wire are shown in figure 3:
Figure 3. Current induced amplitudes in different incident directions.

As can be seen from figure 3, when irradiated from the nose or tail of the aircraft, the cable coupling current is about 15dB compared with that from the side of the aircraft. The foremost reason is that the radiation field intensity is different due to the shielding efficiency of the body in different directions. The second factor is that the polarization direction of electric field changes from vertical incidence to parallel cable incidence. When the electric field is parallel to the cable, the coupling effect is strong[10,11].

4.2 Influence of uniform plane wave polarization mode on coupling

When the incident direction is horizontal polarization and vertical polarization, the induced current simulation results of the cable core wire are shown in figure 4:

Figure 4. Amplitude of current induction at different polarization modes of plane waves.

The coupled current in the horizontal polarization is higher than that in the vertical polarization cable. Interference protection of the vertical wave on the cable should be considered in the design and test.

4.3 The influence of cable length on coupling

When the cable length is 1m, 3m and 5m respectively, the induced current simulation results of the cable core wire are shown in figure 5:
When the cable length is 1, 3, and 5m, the amplitude of the induced current on the cable increases and decreases, except for the amplitude of the current at the resonant frequency point. Generally speaking, the longer the cable is, the greater the induced current will be.

4.4. The effect of cable radius on coupling
When the cable radius is 1mm, 3mm and 5mm respectively, the induced current simulation results of the cable core wire are shown in figure 6:

There is no significant difference in induced current between single wires of different thickness, and the coupling current of the wire with a large radius is slightly larger than that of the single wire with a small radius.

4.5. The effect of cable type on coupling
When the cable types are single core wire, shield wire (shield layer conductor = 1x105S/m, thickness: 0.25mm) and RG58 coaxial (single layer shield wire), the induced current simulation results of the cable core wire are shown in figure 7:
Figure 7. Current induced amplitudes of different types of cables.

Under the same irradiation condition, the cable after adding the shielding layer is very close to the frequency domain waveform of the coupled current on the single-core wire of the same specification. In terms of amplitude, except for some resonance points, the shielding performance is about 30dB higher than that of the single-core wire. Coaxial cable is the least inducted contemporary among the three lines and has strong anti-interference performance.

4.6. The impact of installed location on coupling
When the cable assembly position is the top and bottom of the machine respectively, the induced current simulation results of the cable core wire are shown in figure 8:

Figure 8. Current induced amplitudes at different installation locations.

The installed position of the cable will have a certain influence on the coupling current of the cable, which can be up to nearly 10dB.

4.7. The influence of gap structure on coupling
When there are no gaps in the body structure, 500mm×5mm slit and 500mm×10mm slit, the induced current simulation results of the cable core wire are shown in figure 9:
When there are gaps in the body, the coupling current of the cable increases obviously and the position of the coupling resonance point changes, which are mainly caused by the change of the shielding efficiency of the body. With the increase of the gap area, the coupling current increases slightly, but the frequency domain waveform is basically unchanged.

5. Conclusion
In this paper, electromagnetic computing software FEKO was used to analyze the coupling characteristics of cables under the action of HIRF under different conditions. The conclusions are as follows:

1. With the increase of the frequency of the incident field, the induced current has a tendency to increase in general, and the induced current will suddenly increase at some frequency points due to the resonance effect.

2. When a high field intensity irradiates the body, the radiation direction and polarization mode will have a significant impact on the result of cable coupling, so it needs to be paid more attention to in the test.

3. The length and radius of the cable have negligible influence on the coupling of the cable. The induced current of a single wire with a large radius and a long length is slightly larger than that of a single wire with a small radius and a short length;

4. Shielding cable has a better shielding effect than the single-core cable, with a difference of about 30dB. The induced current can be greatly diminished by the use of shielding wire, and the induced current is very small when coaxial cable is used at the same time.

5. The structure of the body and the assembly position of cables will affect the coupling of cables. During the layout of cables, the location with superior shielding efficiency of the body should be selected as far as possible, away from the high-power launching equipment on board, so as to reduce the risk of coupling interference of cables.

References
[1] Gao tianzhu. Significance of L/HIRF protection for modern aircraft and maintenance items[J]. China science and technology expo, 2009 (34) : 94-95.
[2] Tang Jianhua. New requirements for aircraft development - on high intensity radiation field (HIRF) protection [J]. International aviation, 2007 (11) : 65-66.
[3] RTCA/DO-160F. Environmental conditions and test procedures for airborne equipment[S]. 2007.
[4] Xie Yujing. Application of electromagnetic numerical calculation method in the protection of civil aircraft HIRF [J]. Journal of science and technology innovation, 2017, 14 (16) : 24-26.
[5] Yan Zhaowen, Su Donglin, Yuan Xiaomei. FEKO5.4 electromagnetic field analysis technology and case analysis [M]. Beijing: China water resources and hydropower press, 2009.
[6] Lu Yinghua, Wang Xuying. EMC analysis method and calculation model [M]. Beijing: Beijing university of posts and telecommunications press, 2009.
[7] Wang Yizhe, Wang Zezhong, Liu Hua et al. Coupling Mechanism of Shielded Cables by
Transient Electromagnetic Fields[J]. High Voltage Engineering, 2009, 35(8): 1957-1962.

[8] Ridel M, Savi P. Parmantier. Characterization of Complex Aeronautic Harness-Numerical and Experimental Validations[J]. Electromagnetics, 2013, 33(5):341-352.

[9] Gao Wei, Liang Zichang, Gao pengcheng. Fast simulation of HIRF effects in aircraft cabin and measurement research[J]. Guidance & Fuze, 2014, 35(3):38-41.

[10] She Yunfeng, Hou Naixian, Yang kun. Simulation study on electromagnetic coupling of cables in aero-engine control system [J]. Aero-computing technology, 2018, 48(02):66-69+74.

[11] Ma Jinping, Mao Naihong, Ding Jun et al. Field-to-Twisted Pair Electromagnetic Coupling Study [J], Chinese Journal of Radio Science, 1998, 13(1): 93-96.