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RESEARCH ON CROSSTALK CHARACTERISTICS OF AIRCRAFT ELECTRICAL CABLE

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Abstract

Aircraft electrical wiring are responsible for the transmission of electrical energy and signals. Due to the limited internal space, wiring bundled together, and the conduction coupling may interfere with the normal operation of systems and equipment inside the airplane, causing electromagnetic compatibility problems. This paper analyzes the electromagnetic field strength of different types of aircraft cables coupled to space, and discusses the shielding effect of the wave proof jacket often used in the actual installation process, which can provide guidance for the installation and selection of cables in aircraft.

Keywords: electrical wiring, coupling interference, shielding

1. General Introduction

Aircraft cables are mainly used for the connection of power supply system and electronic system, and are the transmission path of internal electric energy transmission, control signal and low-frequency analog signal of aircraft Among them. The structure of aircraft electrical cable is mainly composed of single core insulated wire and shielded cable with sheath.

With the rapid development of electronic technology and aviation manufacturing technology, all kinds of high-power, high integration and high sensitivity electronic equipment have been widely used in aircraft. Compared with traditional mechanical equipment, electronic equipment is more sensitive to the electromagnetic environment [1]. Various aircraft electromagnetic compatibility problems are emerging, and even affect flight safety [2-3]. According to statistics, about 60% of various electromagnetic interference problems on aircraft are caused by electromagnetic coupling between cables [4-5]. The cables inside the aircraft are usually bundled into bundles. There are different degrees of crosstalk between the bundled cable harnesses, coupling the signal in the cable to other cables in the accessories to generate interference signals, resulting in degradation of equipment performance and even endangering flight safety [6-7]. In view of this phenomenon, this paper studies the crosstalk characteristics of cables through design tests.

2. Analysis of cable crosstalk coupling principle

The crosstalk between cables is mainly expressed in the form of mutual inductance and mutual capacitance, which is divided into inductive coupling and capacitive coupling [8].

2.1 Inductive coupling analysis

The changing current on the cable will cause the surrounding magnetic field to change. Since other cables in the cable bundle are close to the cable, the generated changing magnetic field may be coupled with these adjacent cables and induce voltage on them, resulting in interference. The changing current is in direct proportion to the coupled current, and its ratio is the magnetic flux, and its relationship with the current is as follows.

$$\emptyset = L \times I \tag{1}$$

L is the inductance of the circuit. When there are two parallel cables, the equivalent circuit of the inductance is shown in the figure below.

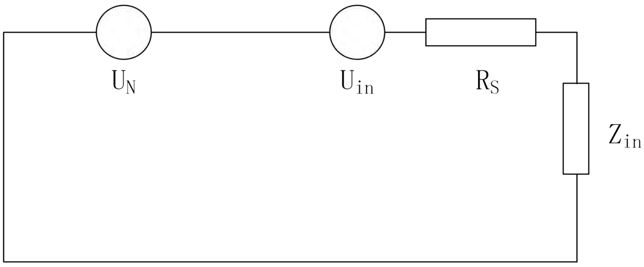


Figure 1 – Equivalent circuit diagram of inductive coupling model.

When the current in cable 1 generates magnetic flux in another parallel cable 2, mutual inductance M_{12} will be formed in the two circuits.

$$M_{12} = \frac{\emptyset_{12}}{I_1} \tag{2}$$

The above formula is the magnetic flux generated by cable 1 in cable 2. According to Faraday's law, the voltage U_N generated by the magnetic flux induced by the current of cable 1 in cable 2.

$$U_N = \frac{d}{dt}\int_S \vec{B} \cdot d\vec{s} = j\omega\emptyset_{12} = j\omega M_{12} I_1 \tag{3}$$

From the above formula, it can be obtained that the voltage U_N generated by the coupling of the disturbed cable is proportional to the frequency ω, mutual inductance M_{12} and the current in cable 1. Generally, when the cable bundle is tied and the interference current remains the same, the higher the interference current frequency, the greater the coupling interference to another cable.

2.2 Capacitive coupling analysis

For cable bundles parallel to each other, parasitic capacitance will be formed between two cables. When the voltage on one cable changes, the changed electric field will be coupled with a nearby cable, and a voltage will be induced to generate interference. The capacitive coupling between the two circuits can be equivalent to the circuit diagram shown in Figure 2.

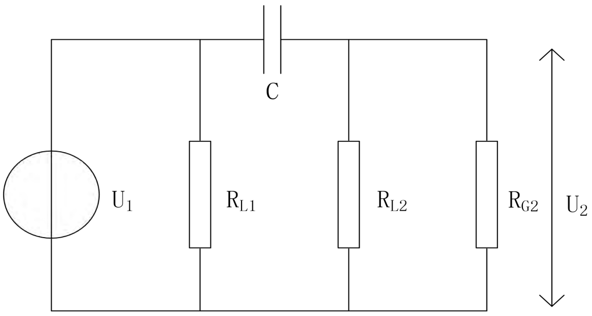


Figure 2 – Equivalent circuit diagram of capacitive coupling model.

U_1 and R_{L1} are the equivalent voltage and transmission impedance of the interfering cable 1 respectively, R_{L2} and R_{G2} are the transmission impedance of the sensitive cable to the ground, and C is the inductive capacitance formed between the two cables. Assuming that the voltage U_1 of cable 1 causes coupling interference to cable 2, the coupling voltage U_2 on cable 2 can be obtained from the equivalent circuit in Figure 2.

$$U_2 = \frac{R_2 U_1}{R_2 + X_C} = \frac{j\omega C R_2 U_1}{1 + j\omega C R_2} \tag{4}$$

Among them:

$$R_2 = \frac{R_{G2} R_{L2}}{R_{G2} + R_{L2}}$$

$$X_C = \frac{1}{j\omega C}$$

When the capacitance generated by coupling is small, $\omega C R_2 \ll 1$, equation (1) is:

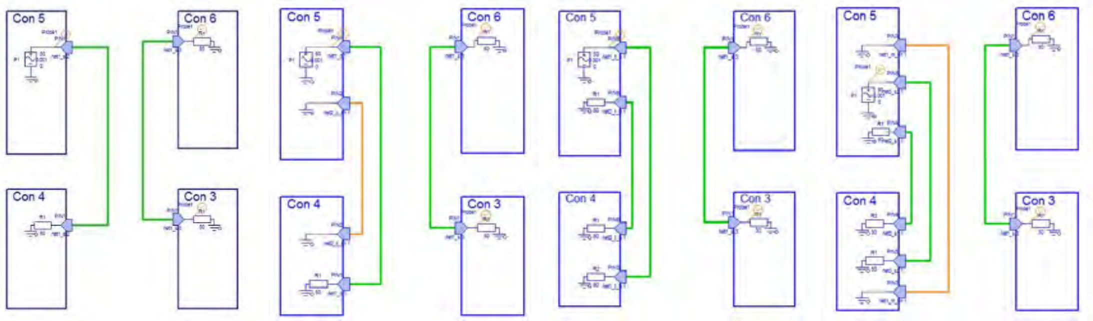
$$U_2 = j\omega R_2 C U_1 \tag{5}$$

From the above formula, it can be obtained that the voltage generated by the coupling of the disturbed cables is proportional to the operating frequency ω of the interference source, the transmission impedance R_2 of the sensitive circuit, the capacitance C between the cables, and the voltage U_1 of the interference source. Generally, the capacitance between the cables in the cable bundle remains unchanged. When the interference voltage is constant, the higher the interference frequency, the greater the coupling interference to another cable.

3. Simulation analysis

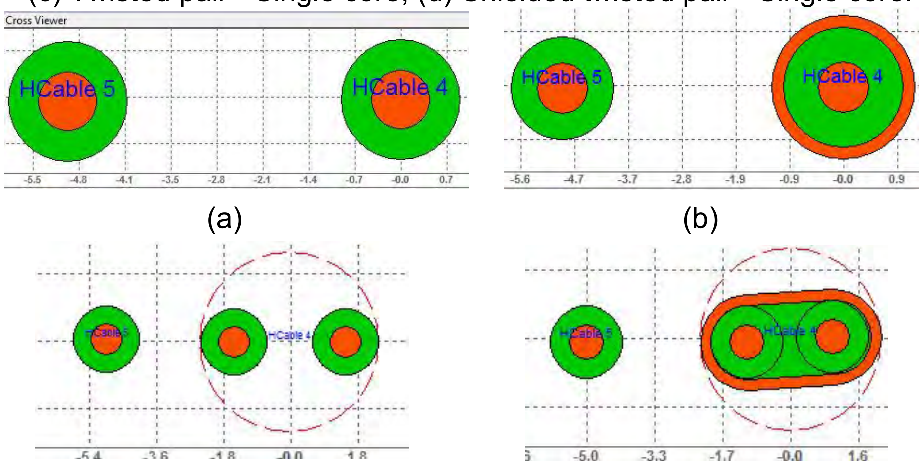
According to the theoretical analysis of the cable coupling characteristics, this paper designed a cable crosstalk model. The model includes cable, grounding desktop, one spectrometer, one signal source and two 50 Ω matching loads. The equivalent model is established as shown in the figure below, and the equivalent circuit model of the spectrometer and signal source is designed. Among them, the length between the two cables is 1m long in parallel.

Through the setting of cable type and spacing, as well as the design of cable port, the change of spacing between cable type and cable parallel is realized, and the conducted interference phenomenon is simulated and analyzed. The circuit design diagram of the cable port is shown in Figure 3. One end of the port is connected to a 50 Ω load, and the other end is connected to a signal source with an equivalent resistance of 50 Ω. The output power is 1mW. The cable model is shown in Figure 4.



(a) (b) (c) (d)

Figure 3 – Cable simulation circuit: (a) single core single core; (b) Coaxial line - Single core; (c) Twisted pair - Single core; (d) Shielded twisted pair - Single core.

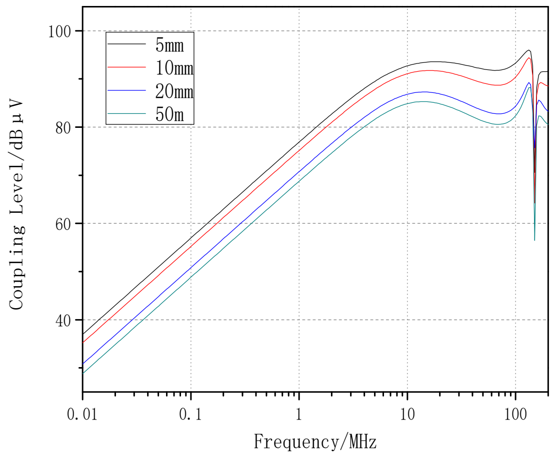


(a) (b)

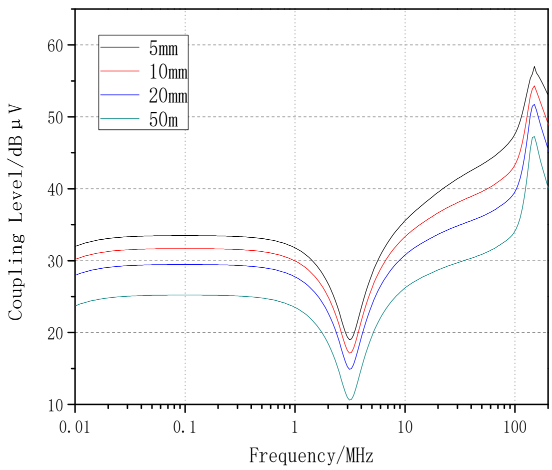
(c) (d)

Figure 4 – Simulation cable setting: (a) single core wire; (b) Shielded single core wire; (c) Twisted wire; (d) Shielded twisted wire.

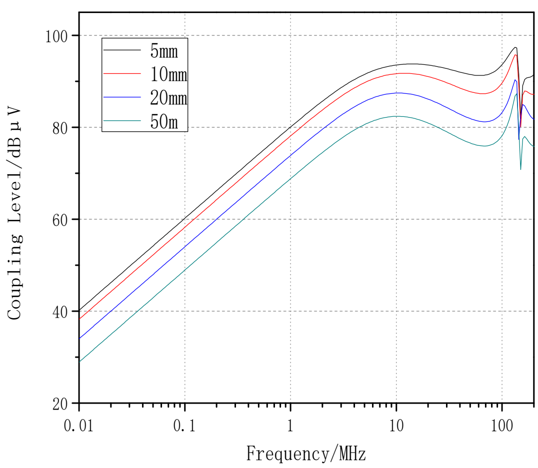
In this paper, the cable models of 1m long single core wire, twisted pair (one of which is grounded), shielded single core wire and shielded twisted pair are set up, and the corresponding cable port circuit models are designed. One end of the port is connected with a 50*Ω* load and one end is connected with a signal source with an equivalent resistance of 50*Ω*, and the output power is 0dBm. Explore the relationship between crosstalk level and interference source frequency by changing cable spacing from 5mm-50mm and cable type. According to the simulation results shown in Figure 5, it can be seen that when the cable spacing is certain, the interference coupling level increases with the increase of frequency. When the high frequency is about 100MHz, the circuit forms a high-frequency oscillation because its signal wave is far longer than the circuit length. From the spacing of 5mm-50mm, the conducted interference coupling electricity of the four groups of cables attenuates on average with the increase of distance. When the cable spacing exceeds 10mm, the cable coupling level drops significantly. At this time, the capacitive coupling drops significantly. When the cable spacing increases to 50mm, the four cable coupling levels drop about 15dB on average compared with the 5mm cable spacing, and the effect is more obvious.



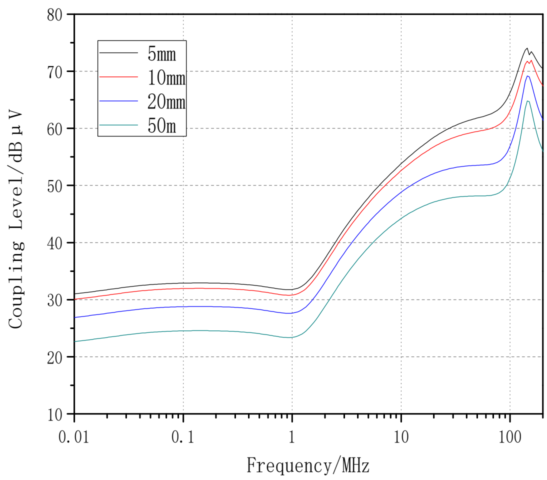
(a)



(b)



(c)



(d)

Figure 5 – Crosstalk characteristics simulation results: (a) single core wire; (b) Shielded single core Wire; (c) Twisted wire; (d) Shielded twisted wire.

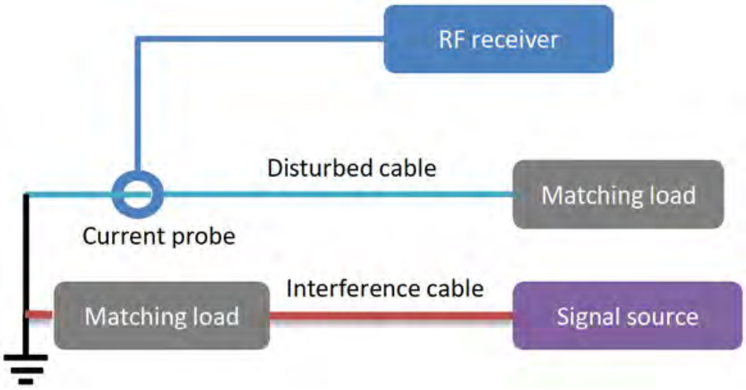


Figure 6 – Crosstalk Test diagram

Figure 6, this paper constructs an experimental method to verify the above simulation by using RF receiver, signal source, load and other test equipment. The results are shown in Figure 7. Through the test verification of various types of cables, the trend of the overall test curve is consistent with the simulation curve, and the error control is good. The simulation results are generally reliable, and further verify the effects of various types of cables, spacing parameters, frequency and other factors on the coupling strength of conducted interference. For all kinds of signals inside the aircraft, especially high-frequency RF signals, the conductive coupling level on the single core line can not be ignored, which is very easy to cause electromagnetic interference. At the same time, increasing the distance between cables as much as possible is an effective means to reduce crosstalk interference.

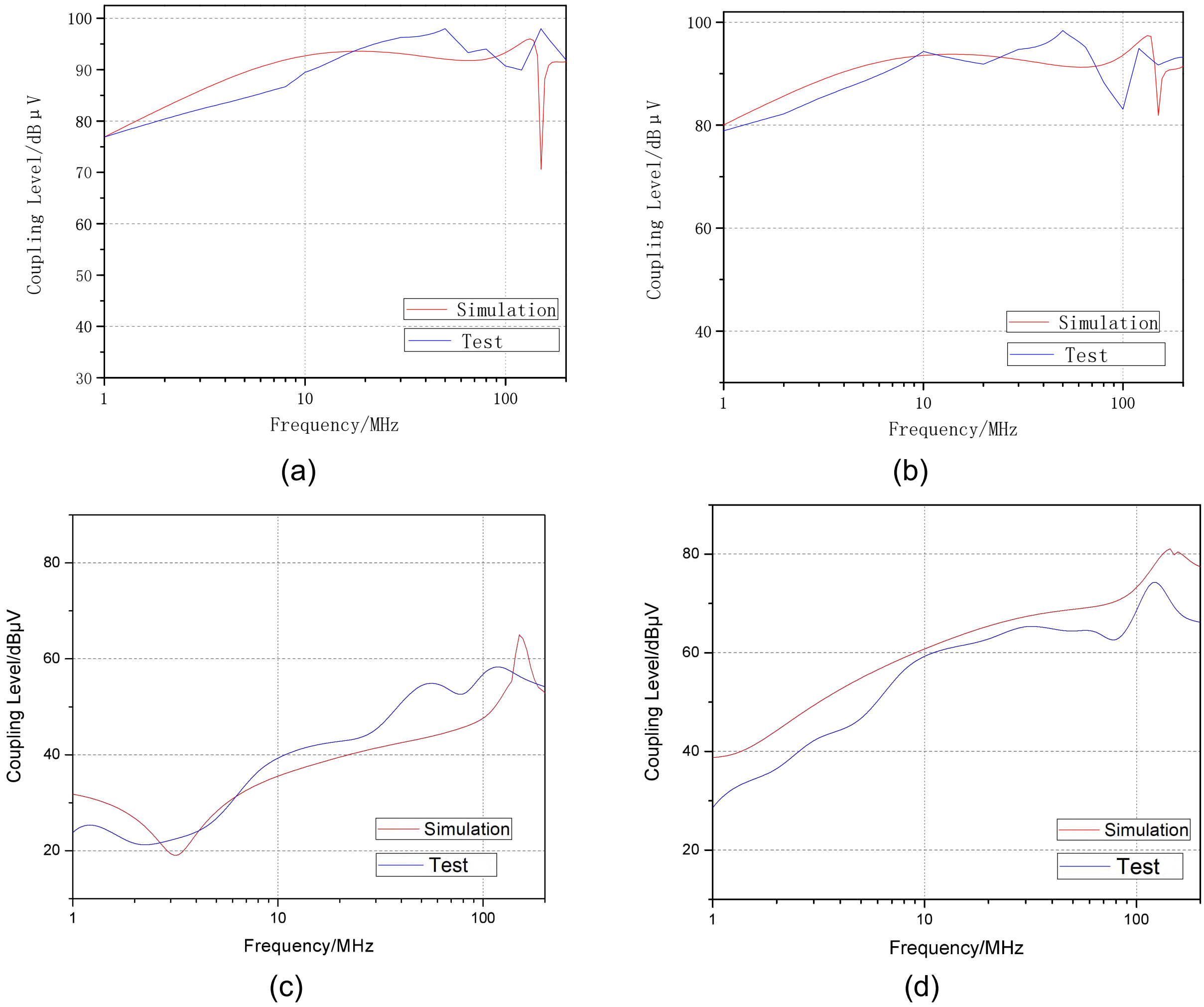


Figure 7 – Actual test verification results: (a) single core wire; (b) Shielded single core wire; (c) Twisted wire; (d) Shielded twisted wire.

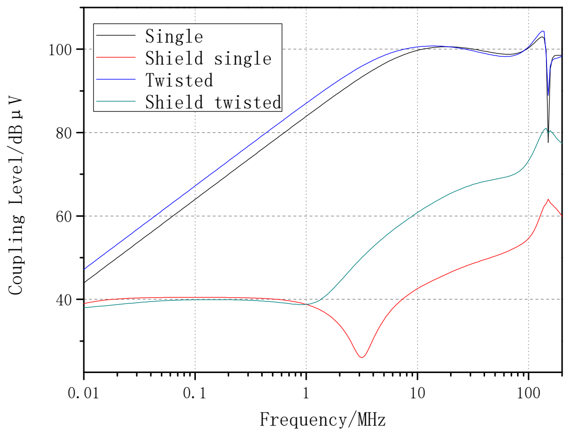
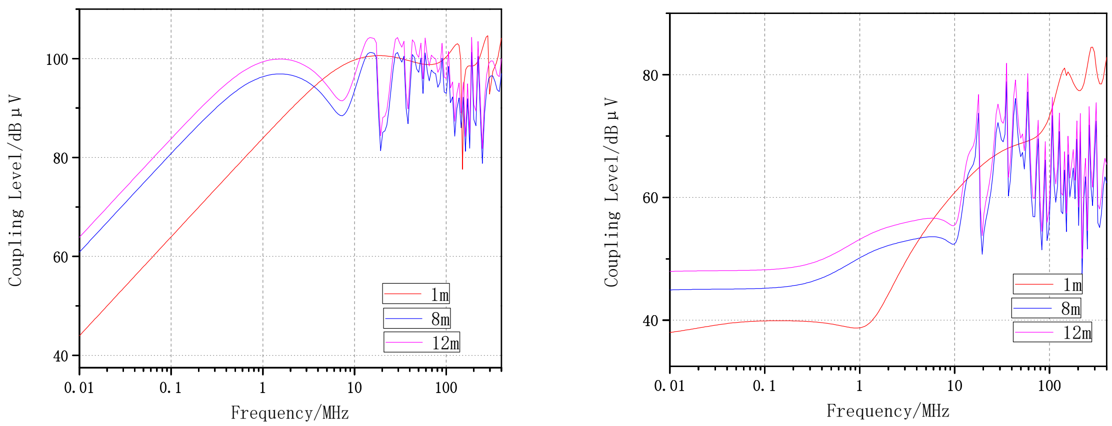


Figure 8 – Crosstalk coupling of different types of cables.

The common cable crosstalk coupling on aircraft is discussed, as shown in Figure 8. Shielded cables can play a good role in attenuating crosstalk at low frequency. When the frequency is greater than 1MHz, it has an effect of about 30-40dB. Since the complete aircraft cable length is usually much longer than 1m, the length of the cable itself is positively correlated with the coupling level, as shown in Figure 9. The crosstalk coupling level of a 12m long cable is significantly higher than that of a 1m long cable, indicating that the longer the aircraft cable is, the more it is necessary to consider the possible crosstalk interference.



(a) (b)

Figure 9 – Simulation results of conductive coupling of cables with different lengths:
(a) single core wire; (b) Shielded single core wire.

As shown in the Figure 10, combined with the actual cable installation process of the aircraft, this paper discusses the treatment method of peeling off the shielding layer of the shielding cable. For cable installation subject to installation environment and process restrictions, it is usually necessary to peel off the shielding layer. Obviously, for a 10m long shielded cable, the complete shielding layer has the lowest coupling level and the best anti-interference ability. For cables with stripped shielding layer, the coupling level difference is small at low frequency. As the frequency increases, the longer the stripped shielding layer, the stronger the coupling level and the weaker the ability to resist electromagnetic interference. For example, the coupling level of stripping 0.01M long shielding layer is far lower than that of stripping 5m long cable. In the meantime, the longer the length of the stripped shielding layer is, the lower the starting frequency of the coupling level higher than that of the complete shielding layer is.

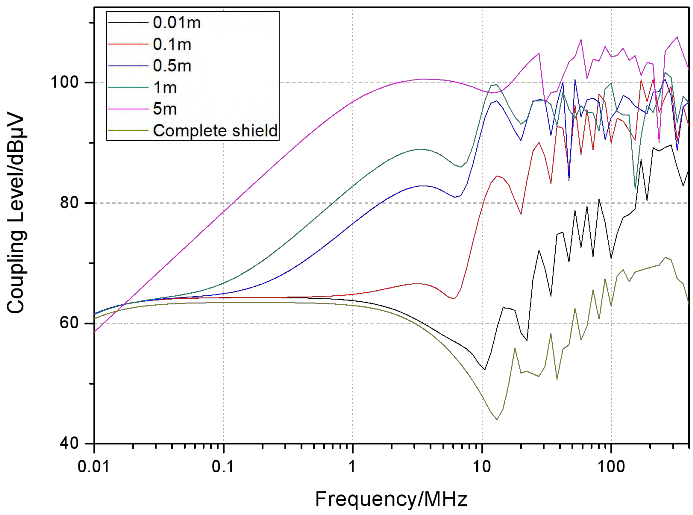


Figure 10 – The relationship between crosstalk level and the length of stripped shielding layer of single core shielded cable.

According to the existing simulation results, it can be roughly concluded that the coupling level of crosstalk is positively correlated with the length of stripped shielding layer. In engineering applications, the measures of stripping the shielding layer during the installation of aviation cables are often remedied in the form of additional wave proof jacket, but at present, there is a certain blindness in the effect of compensation and the measures taken, which are also discussed in this paper.

From the simulation results shown in Figure 11, this paper discusses the coupling level of the 10m long shielded cable with half of its length stripped and wave proof jacket installed. Compared without wave proof jacket, it can be concluded that, the coupling level generated by peeling off the shielding layer can be attenuated to a certain extent by adding the wave proof jacket. Especially at low frequency, the shielding effect has little correlation with the binding gap of the wave proof jacket, while at high frequency, the larger the gap of the wave proof jacket, the worse the shielding effect. For example, the coupling level of the cable with a gap of 9.1mm in the external wave proof jacket is about 30dB higher than that of the cable with a gap of 0.1mm at high frequencies. Therefore, the installation of the wave jacket should be as long and tightly tied as possible.

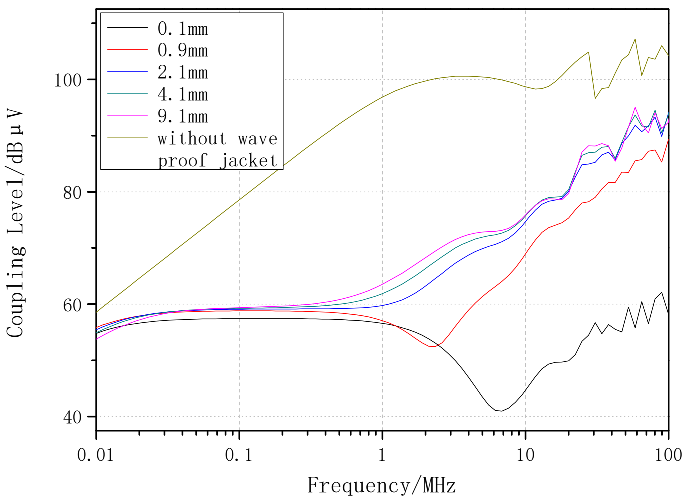


Figure 11 – The relationship between crosstalk level and the gap of external wave proof jacket.

The coupling characteristics of conducted interference of aircraft cables have been discussed, and the key factors, like frequency, cable spacing, length, cable and so on, which affecting crosstalk have been combed by the research. In view of the compact internal structure of the aircraft and the fact that a large number of cable harnesses are bundled, it is difficult to increase the cable spacing, and the conducted interference coupling can not be ignored. Especially for high-frequency cables, corresponding shielding measures shall be taken. The installation of wave-proof jacket in the actual installation of cables is also discussed, which provides some technical guidance for the electromagnetic compatibility design, engineering application and interference control of aircraft cables.

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5. Copyright Statement

References

[1] Z. Li, L. L. Liu, J. Yan, et al. An Efficient Simplification Scheme for Modeling Crosstalk of Complex Cable Bundles Above an Orthogonal Ground Plane. *IEEE Transactions on Electromagnetic Compatibility*, vol. 55, no. 5, pp. 975-978.

[2] D. Nitsch, M. Camp, F. Sabath, et al. Susceptibility of some electronic equipment to HPEM threats. *IEEE Transactions on Electromagnetic Compatibility*, vol. 46, no. 3, pp. 380-389.

[3] Xue Menglin, Xue chen. Research on EMC test technology of aircraft wireless system. *Electronic measurement technology.* Vol. 41, No. 9, pp 50-55, 2001.

[4] Yang kejun. *Electromagnetic compatibility principle and design technology.* People's Posts and Telecommunications Press, 2004.

[5] Kouassi A , Bourinet J , Lallechere S , et al. Safety assessment of a transmission line with EMC requirements. *General Assembly & Scientific Symposium*. Beijing, Vol. 1, No. 1, pp 1-4, 2014.

[6] Fiorif, Musolinof. Comparison of IC conducted emission measurement methods. *IEEE Transactions*, Vol. 52, No. 3, pp 839-845, 2003.

[7] Parmanter J P. Numerical coupling models for complex systems and results. *IEEE Transactions,* Vol. 46, No. 3, pp 359-367, 2004.

[8] Clayton R. Paul. A Brief History of Work in Transmission Lines for EMC Applications. *IEEE Transactions on Electromagnetic Compatibility*, Vol.49, NO.2, pp 237-252, 2007.