Progress of Electromagnetic Compatibility Design for Unmanned Aerial Vehicles

Yong WU* and Qi-shuang MA

College of Automation Science and Electrical Engineering, Beijing University of Aeronautics and Astronautics 100073

*Corresponding author

Keywords: UAV, EMC, Crosstalk, System level, Radiation, Conduction.

Abstract. The electromagnetic environment of UAV system was studied, and three key elements of electromagnetic interference (EMI) are analyzed. The research status of electromagnetic characteristics of UAV system at home and abroad was summarized from numerical simulation of EMI, experimental test of EMI and design of electromagnetic compatibility (EMC). The main contents include the research on electromagnetic characteristics of airborne antenna, EMI of data link and its mechanism, electromagnetic characteristics of internal cables, electromagnetic radiation test, electromagnetic conduction test, system-level EMC design, etc. The key technical challenges faced by the research on EMC of unmanned aerial vehicles at home and abroad are pointed out.

Research on Electromagnetic Environment

When UAV is flying, it is not only affected by electromagnetic environment caused by radiation of internal equipment, but also by external electromagnetic environment such as lightning, interference station, nuclear electromagnetic pulse and so on. The radio frequency radiation overlaps in space, time, frequency and energy with the different working environment of UAV. If these interference cannot be prevented reasonably, the performance of airborne equipment will be greatly affected[1,2]. These EMI will not only interfere with the normal work of the UAV electronic system, but also destroy the key components of the electronic equipment, resulting in the failure of the instrumentation or control system, which directly threatens flight safety.

Electromagnetic environment refers to the sum of power or field interference in different frequency range and the kinds and states of various interference sources when the UAV is performing its mission[3]. The external electromagnetic environment of UAV can be divided into natural electromagnetic environment and man-made electromagnetic environment. Natural electromagnetic environment exists objectively, including lightning, static electricity and earth electromagnetic field; human-made electromagnetic environment is formed by human activities, including electromagnetic wave emission, receiving activities caused by wireless communication and additional electromagnetic fields generated by these activities. The internal electromagnetic environment of UAV mainly includes antenna feed system, electromechanical system and circuit system.

EMI and EMC

EMI source, interference propagation path and sensitive equipment are called as three elements of EMI. Among them, EMI source refers to any component, equipment, system or natural phenomenon that produces interference, including intentional and unintentional emission; interference propagation means the medium that transmits EMI energy to sensitive equipment, which can be divided into conduction coupling and radiation coupling; sensitive equipment refers to the circuit and equipment that are susceptible to interference [4,5].

EMC refers to the electromagnetic environment in which the equipment or system meets the requirements and does not produce unbearable EMI to other equipment. According to the definition, EMC needs to satisfy three conditions: the electromagnetic disturbance generated by equipment or
system in normal operation cannot cause the performance degradation of other equipment; the electromagnetic disturbance generated by other equipment in electromagnetic environment has a certain tolerance; the electromagnetic disturbance that can not affect its performance degradation. Generally speaking, EMC is a subject that studies the coexistence and normal operation of various devices or systems in a specific working environment and limited spectrum resources.

**Current Research Situation at Home and Abroad**

**Numerical Simulation of Emi of Uav**

**Study on Electromagnetic Characteristics of Airborne Antenna.** Airborne antenna layout is one of the EMC design of UAV. Inter-antenna coupling, antenna pattern and near-field radiation have a great impact on the performance of airborne multi-antenna system, and are the main indicators to measure the layout of aircraft multi-antenna system. Among them, the coupling degree between antennas is the most important parameter to measure the EMC between antennas.

In the initial stage of antenna design and installation, through precise theoretical analysis, Tan Yuanyang[6] predicted the installation location of antenna. So the installed antenna not only meets the aerodynamic requirements of aircraft, but also achieves their main technical and tactical indicators and EMC between antennas. Yuan Jun[7] adopted adaptive fast multipole algorithm to solve the linear structure, analyzed the EMC pattern, isolation, interference power and other important indicators of airborne antenna system, gave the specific process of EMC analysis of large platform antenna system, and combined with engineering examples, applied the numerical algorithm and model. Chen Jinji[8] proposed two methods for calculating antenna isolation. Eight airborne antennas were designed by HFSS simulation. The electromagnetic characteristics of each antenna were analyzed and the rationality of the simulation was verified. In addition, the influence of antenna function, working frequency, installation position and radiation pattern on antenna coupling degree was analyzed, and the isolation degree between UHF radio antenna and other antennas was calculated. Peng Tianhao[9] analyzed the EMI caused by the radio frequency excitation source in the meter-wave broadband plasma antenna and the overload of the instrument, the harmonic distortion of the measuring equipment and the harmonic noise in the communication frequency band. Aiming at the special application of wide range variable load in plasma antenna, the method of wide load plasma harmonic filtering was studied. The filter designed according to law was applied to the actual antenna system, which solved the problem of instrument overload and harmonic distortion of measuring equipment, and effectively suppresses the harmonic amplitude of interference in the communication frequency band. Liu Baihan [10] studied the numerical simulation technology of airborne antenna in radio frequency band on aircraft. A set of radio frequency compatibility simulation algorithms suitable for typical airborne antennas was formed by comparing and analyzing the simulation results of different algorithms and different frequencies. Based on the finite difference method, Han Xuefeng[11] obtained the antenna pattern affected by the airframe and the layout design, and through the analysis of the electromagnetic radiation characteristics of the airborne antenna, obtained the optimum electromagnetic field distribution and antenna distribution area.

**Research on EMI and Its Mechanism In Data Link.** UAV airborne receiver is composed of multistage amplifier, mixer and filter. For UAV upstream data link, if the interference signal intensity entering the airborne receiver is large enough to exceed the dynamic range of various electronic devices in the receiver, the sensitivity of the receiver will be reduced and the signal-to-noise ratio will be reduced, which can be called blocking interference [12].

Unmanned aerial vehicle (UAV) communication is highly dependent on data link and vulnerable to battlefield electromagnetic environment during its mission. In UAV data link system, the receiver is sensitive to EMI[14,15]. EMI will cause the non-linear distortion of airborne receivers, which will
lead to the interruption of data link communication and seriously threaten the battlefield survival of UAVs.

In China, UAV data link interference prediction and anti-jamming technology are studied. Guo Shuxia[16] proposed an adaptive coding and modulation method for UAV data link, which improved the reliability and effectiveness of UAV data link information transmission. Huang Wenjun[17] proposed a new anti-jamming technology for UAV data link. Jiao Yanwei[18] used cloud model method to study the comprehensive effectiveness of UAV in complex electromagnetic environment, and established the effectiveness evaluation index system of hierarchical structure of UAV in complex electromagnetic environment. Liu Ruiqi et al.[19] deduced the inequality of tracking interference hyperboloid and limited power interference range from the time domain and power condition of tracking interference, determined the effective interference range under different parameters, and proposed a reasonable jamming start-up strategy. Guo Hongjing[20] studied the cognitive strategy and cognitive process of UAV TT&C link interference. The estimation of period and duty cycle of impulse noise interference and improved FCME detection algorithm were studied by using time domain interference detection algorithm and frequency domain interference detection algorithm respectively. Zhang Xiaodong et al.[21] carried out the upstream main remote control lock-out sensitive frequency point injection method research, obtained the spectrum change rule of useful signal after interference, and obtained the lock-out mechanism through BPSK modulation and demodulation analysis. Guo Shuxia et al.[22] developed a scene view method based on GRA and the dynamic real-time driving method of microwave instrument according to the performance of real-time simulation and the intelligent function of simulation system in 2013, and simulated the dynamic interference of static radiation antenna in microwave anechoic chamber. Shen Yan'an[23] used Simulink simulation platform to build the UAV remote control link model based on direct spread spectrum technology. The capability of UAV remote control link against various interference was evaluated. Based on the antenna coupling probability model and the possible maximum coupling loss between the interference source and the data chain, Song Zuxun et al. [24] calculated the interference probability or the number of received interference pulses, and compared with the fault-tolerant ability of the data chain.

**Numerical Simulation of Electromagnetic Characteristics of Internal Cables.** Wire plays an important role in the EMC of UAV. Connections between electronic devices, between electronic devices and systems, between systems and power supplies need wires. Wires can be equivalent not only to receiving antennas, but also to transmitting antennas, which makes the electromagnetic environment around them complicated[25,26]. According to statistics, the total weight of all kinds of cables on a large transport aircraft reaches several tons, and 60% of all kinds of EMI occurring on the aircraft is due to the electromagnetic coupling between cables [27].

Jiangdan[28] used three-dimensional electromagnetic simulation software CST to model and simulate the electromagnetic characteristics of cables inside the aircraft. The results show that the farther the cables are from each other, the closer they are to the metal floor, the shorter the length of the cables, and the smaller the crosstalk to other cables. Wang Chao[29] modeled and simulated the electromagnetic coupling characteristics of aircraft interconnected cables. The results show that the electromagnetic coupling between cables decreases with the increase of distance and height from the ground, increases with the increase of frequency. Tan Yujian[30] studied the frequency domain solution method BLT equation and applied it to the analysis of transmission line crosstalk with arbitrary layout; also studied the time domain solution method-FDTD method, and deduced the iteration formula under lumped source loading and distributed source loading.

**EMI Test of Unmanned Aerial Vehicle**

**Measurement of Electromagnetic Radiation.** Radiation interference refers to the interference propagating in the form of electromagnetic waveform. The energy of this kind of interference is due to the radiation of the interference source, which propagates through the medium with the characteristics and regularity of electromagnetic waves. Huang Daqing et al. [31] analyzed and tailored the index of
conduction and radiation test items in the National Military Standard. Through RE101 electromagnetic radiation, RE102 electromagnetic radiation and RE103 electromagnetic radiation test, it was determined that the magnetic field emission of EUC would be induced to nearby sensitive cables and equipment, which laid a foundation for future EMC test standard of UAV. Song Huixuan et al. [32] established the transmission line model of the cable harness. The surface current distribution of the cable harness was calculated by using the multi-conductor transmission line model. The accurate calculation formula of the radiation intensity was obtained by using the mirror method. The electromagnetic radiation environment of the cable harness in the aircraft was obtained. It has certain reference value for optimizing the EMC design of the aircraft. Zhang Dongxiao et al. [33] took a certain type of unmanned target aircraft as the experimental object, built the test system by using the simulator construction method, put forward the radiation effect evaluation index and designed the dynamic monitoring system. Through the continuous wave electromagnetic radiation test of target, it is found that the unlocked frequencies of main channel and secondary channel data are mainly concentrated near their respective operating frequencies. Li Hongxiang [34] designed a test method to test the radiation disturbance and radio frequency magnetic field radiation immunity of UAV products, and built two test equipments. In the 3-meter method anechoic chamber, the radiation disturbance and radio frequency magnetic field radiation immunity of UAV were tested by using the advanced EMC test system, and the limits of radiation disturbance and the radiation endurance of UAV were determined. Radiation immunity level of frequency magnetic field.

Electromagnetic Conduction Test. From the analysis of transmission channels, conducted interference can be divided into capacitance conduction coupling, resistance conduction coupling and inductance conduction coupling. Huang Daqing et al. [32] measured the conductive emission of the input power line of the tested equipment, aiming at the theoretical analysis and tailoring of the conductive emission CE101 of the power line, the theoretical analysis and tailoring of the conductive emission CE102 of the power line, and the theoretical analysis and tailoring of the conductive sensitivity CS101. Zhao Limin [35] deduced the INS heating model by system identification method, which provided a model basis for conduction interference analysis. After modeling typical loads, a new design method of crosstalk between ports in power supply system was analyzed by using the concept of transfer impedance and transfer admittance in multi-port network theory. After identifying the simplified model of conduction interference in power supply system, it was applied to the analysis of conduction interference. In the simulation model of power supply system, the actual working state of power supply system was simulated. By optimizing the simulation test parameters, the suppression measures and means to suppress all kinds of conductive interference were put forward. Xu Ming et al. [36] conducted conduction sensitivity analysis and design on the basis of functional design. The improved power filter, RS232, PCB chip and cable design circuit or schematic diagram were given. Through the test of CS101 and CS114 in GJB151A-97 and GJB152A-97, the anticipated purpose is achieved, which provides a reference for the EMC design of aircraft.

Key Technical Issues

Consistency between Heaven and Earth in EMC. At present, most of the EMC characteristics of UAV systems are evaluated by matching test and comprehensive test. The EMC between the in-flight equipment, electrical system and wireless system is verified by testing various states of UAV. However, the test only examines the functions of wireless transceiver devices in different states of UAV, which cannot meet the requirements of Heaven-Earth consistency instead of EMC test. In the course of flight, the electromagnetic environment of UAV is constantly changing. The equipment on the UAV is facing the electromagnetic environment impact caused by the high-power ground wireless equipment, and the electromagnetic environment caused by the wireless equipment in the aircraft and the target. Only by establishing an EMC test platform which is consistent with the actual flight
environment, can it be possible to achieve the consistency between heaven and earth in the EMC test of UAV.

**EMC Intelligent Design Technology.** At present, the EMC analysis of UAV and other aircraft mainly depends on manual work. How to automatically realize the EMC test and evaluation needs the support of EMC expert system. At present, the rapid development of artificial intelligence technology is widely used in robots, UAVs and other high-tech fields, but the EMC test system with artificial intelligence has not yet been reported. It is believed that EMC intelligent technology will be applied to UAV system design in the near future.

**Summary**

This paper studies the electromagnetic environment of UAV system, summarizes the research status of the electromagnetic characteristics of UAV system at home and abroad, and points out the key technical problems and future development trend faced by the design of EMI and EMC of UAV system at present, which can be used as reference for fellow researchers.

**References**

[1] Liu Pengcheng, Qiu Yang. Principle and Technology of EMC [M]. Higher Education Press, 1993.
[2] Cai Rengang. EMC Principle, Design and Prediction Technology [M]. Beijing University of Aeronautics and Astronautics Press, 1997.
[3] Gao Yougang. General Introduction to EMC [M]. Beijing University of Posts and Telecommunications Press, 2001.
[4] V. Prasad Kodali. Engineering EMC: principles, measurements, technologies, and computer models[M]. New Jersey: Wiley-IEEE Press, 2001.
[5] Lu Yuzhong. Research on EMI Coupling and Protection of Small Aircraft in Complex Electromagnetic Environment [D], Xi'an University of Electronic Science and Technology, 2013.
[6] Tan Yuanyang. Analysis of scattering characteristics (cylindrical part) of aircraft antenna by UTD method [D]. Xi'an University of Electronic Science and Technology. 2004.
[7] Yuan Jun. Research on high performance numerical algorithms for electromagnetic scattering and EMC analysis [D]. Xi'an University of Electronic Science and Technology. 2008.
[8] Chen Jinji. Aircraft EMC prediction and simulation [D]. Xi'an University of Electronic Science and Technology. 2013.
[9] Peng Tianhao. Research on the theory and key equipment of the METRE-WAVE broadband plasma antenna [M]. Shanghai Jiaotong University. 2015.
[10] Liu Baihan. Research on numerical simulation technology for radio frequency compatibility of aircraft [M]. Shenyang University of Aeronautics and Astronautics. 2017.
[11] Han Xuefeng, Li Dong. Electromagnetic simulation analysis of airborne antenna based on finite difference time domain method [J]. Communication technology. 2017, 50 (11): 2472-2477.
[12] Li Wei, Wei Guanghui, Pan Xiaodong et al. Prediction method of electromagnetic radiation effects of dual-frequency continuous wave in typical communication equipment band [J]. Systems engineering and electronic technology, 2016, 38 (11): 2474-2480
[13] Guan Weiwei, Zhu Qianwang, Xu Jianzhong. Anti-jamming Analysis of UAV Data Link Based on SIR Equation [J]. Ship Electronic Engineering, 2013, 33 (1): 73-75
[14] Cheng Weilan, Liu Jianqiang, Jianli. Analysis of receiver desensitization mechanism under interference conditions [J]. Ship Science and Technology, 2012, 22 (3): 122-125.

[15] Bai Chunhui, Zhao Lingwei. Effect of Nonlinear Distortion on Communication Detection Receiver [J]. Communication Countermeasure, 2011 (4): 41-43.

[16] Guo Shuxia, Songyang, Hao Jun et al. Research on Hardware-in-the-loop simulation technology of UAV data link adaptive coding modulation method [J]. Computer measurement and control.

[17] Huang W Z, Wang Y S, Ye X Y. Studies on novel anti-jamming technique of UAV data link [J]. Chinese Journal of Aeronautics, 2008(21): 141-148.

[18] Jiao Yanwei, Hou Deting, Zhou Dongfang et al. Evaluation efficiency of UAV in complex electromagnetic environment [J]. Intensive laser and particle beam, 2014, 26 (7): 11-16.

[19] Liu Ruiqi, Yao Zhicheng, Yang Jian, etc. [J]. Study on Start-up Strategy of Tracking Jamming for UAV Remote Control Link [J]. Electro-optic and Control. 2018, 25 (4): 25-27.

[20] Guo Hongjing. Research on interference perception and recognition technology of UAV TT&C link [D]. University of Electronic Science and Technology. 2014.

[21] Zhang Xiaodong, Chen Ya, Xiao Xuerong. Research on EMI mechanism of main remote control data link of UAV [J]. Journal of Microwave Science. 2016, 32 (2): 90-96.

[22] Guo Shuxia, Dong Zhongyao, Hu Zhantao, et al. Simulation of dynamic EMI environment for unmanned aerial vehicle data link [J]. EMC Design and its Application. 2013(8): 19-27.

[23] Shen Yanan. Simulation study on electromagnetic environment adaptability of UAV remote control data link [J]. Value Engineering. 2012 (5): 178-179.

[24] Song Zuxun, Yu Bianzhang. Adaptability of UAV data link to radar EMI [J]. Systems Engineering and Electronic Technology. 2004, 26 (12): 1790-1793.

[25] Yu Jihui. Research on Simulation of crosstalk and radiation of interior conductors [J]. Journal of Systems Simulation, 2008, 20 (17): 4737-4739.

[26] Lin Xiaohuan, Ma Xunming, Lin Gang. EMC Analysis and Measurement in Avionics System [J]. Microelectronics and Computer, 2008, 25 (7): 169-172.

[27] Yang Kejun. EMC Principle and Design Technology [M]. Beijing: People's Posts and Telecommunications Press, 2004.

[28] Jiangdan. Research on electromagnetic conduction and radiation characteristics and suppression methods of multi-electric aircraft system [D]. Nanjing University of Aeronautics and Astronautics, 2016.

[29] Wang Chao. EMI and Airworthiness of aircraft EWIS wiring [D]. Civil Aviation University of China. 2012.

[30] Tan Yujian. Research on EMC analysis method for complex systems [D]. National University of Defense Science and Technology. 2009.

[31] Huang Daqing, Li Bo. EMC Conduction and Radiation Test Project Cutting Method for UAV [J]. Optical Precision Engineering. 2009, 17 (2): 380-387.

[32] Song Huixuan, Wu Gang, Zhu Long, etc. EMC analysis of radiation from cables and cables harness inside aircraft [R]. National Conference on Microwave and Millimeter Wave. 2013: 1532-1535.
[33] Zhang Dongxiao, Chen Ya, Cheng Erwei, et al. Experimental study on continuous wave electromagnetic radiation effects of an unmanned target aircraft [J]. Journal of Hebei Normal University (Natural Science Edition). 2017, 41 (1): 39-44.

[34] Li Hongxiang. Testing of Radiation Disturbance and Radiation Immunity of UAV [D]. Heilongjiang University. 2017.

[35] Zhao Limin. Research on Conducted EMI Analysis Method for Aircraft Electrical System [D]. Harbin Engineering University. 2012.

[36] Xu Ming, Chen Yan. Conduction sensitivity analysis and design of an airborne flight controller [J]. Ship electronics engineering. 2016.