Research on ultra-wideband electromagnetic pulse irradiation effect and protection method of Unmanned Aerial Vehicle

Gao Shukun*, Cheng Erwei, Chen Yazhou, Wang Yuming

National Key Laboratory on Electromagnetic Environment Effects, Shijiazhuang Campus of Army Engineering University, Shijiazhuang, China

*506397978@qq.com

Abstract. The data link is an important guarantee for the Unmanned Aerial Vehicle (UAV) equipment to complete its battlefield functions. Its anti-electromagnetic pulse interference capability directly affects the airborne communication security. Ultra-wideband (UWB) electromagnetic pulse has become an important source of electromagnetic interference due to its high power, wide frequency band and wide interference target. In order to verify the reliability of UAV data link communication under UWB electromagnetic pulse irradiation conditions, the UWB electromagnetic pulse irradiation effect experiment of UAV was carried out, and the mechanism of "lost lock" effect of UAV data link was analyzed. The experimental results show that when the UWB electromagnetic pulse irradiation intensity reaches 140 kV / m, it will cause hardware damage to the UAV, and found that its internal sensitive device low noise amplifier is damaged. In response to this, the comprehensive design of the electromagnetic protection measures for the UAV was carried out, laying the foundation for the next step to strengthen the electromagnetic protection of the UAV.

1. Introduction
With the rapid development of modern science and technology, the development trend of future warfare has gradually evolved into a local war under the conditions of high-tech information technology. In recent years, several high-tech wars in the world shows that information weapons and equipment gradually replaced traditional weapons, becoming the killer of war. UAVs are favored by the military of various countries for their unique advantages such as high mobility, zero casualties, high cost-effectiveness, and flexible and diverse modes of take-off and landing, and have broad application prospects. At the same time, due to the design constraints and other constraints, a large number of electronic frequency devices are distributed in the small space inside the drone's fuselage, and there are many internal electromagnetic sensitive components, so the strong electromagnetic environment is highly integrated. Machine equipment poses a huge threat.

According to the standard of the International Electrotechnical Commission, the high-power electromagnetic field environment is higher than the electromagnetic environment 100V/m. Ultra-wideband electromagnetic pulses have steep rise times, narrow pulse widths and instantaneously released high-intensity pulsed powers. Can break through many protective circuits, interfere with or even damage the normal communication of electronic devices. When the UWB electromagnetic pulse weapon attacks the UAV equipment, it seriously interferes with the normal communication of the data link, which makes it difficult for the UAV to perform the mission command normally, and may even...
crash out of control. Therefore, the development of UWB electromagnetic pulse protection for drones has become an urgent practical need.

2. UAV Ultra-wideband Electromagnetic Pulse Irradiation Effect Experiment

Ultra-wideband electromagnetic pulse is used as the experimental interference source, and a certain type of UAV data link system is taken as the experimental research object. The electromagnetic radiation effect research is carried out, the coupling path of electromagnetic pulse to the UAV is analyzed, and the electromagnetic sensitive unit is found. The man-machine data link lays the foundation for anti-electromagnetic pulse capability.

2.1 Ultra-wideband electromagnetic pulse radiation system

The experimental UWB electromagnetic pulse radiation source is a GW-class ultra-wideband electromagnetic pulse radiation system. The system consists of three parts, namely Tesla type high power pulse source, high power ultra-wide spectrum sub-nanosecond pulse generator and high power UWB radiating antenna. The GW-class UWB electromagnetic pulse radiation device can radiate a single electromagnetic pulse and an UWB electromagnetic pulse train with repetition frequencies of 1Hz, 2Hz, 5Hz, 10Hz, 20Hz, 50Hz and 100Hz, respectively; It can reach 1GW and has a wide spectrum range; it can produce continuously adjustable pulses with a pulse width of 0.5~4.5 ns, a pulse rising edge less than 1 ns, and an ultra-wideband electromagnetic pulse radiation field with a vertical direction of electric field polarization.

The relationship between the radiation field strength of the UWB electromagnetic pulse radiation emission system and the distance with the radiation source is as follows:

\[ E = \frac{1020}{x + 2.5} \left(1 - e^{-0.75x}\right) \]

Where \( x \) is the distance from a point in the radiation field to the front end of the feed, in units of m; \( E \) represents the electric field strength in the radiation field, in units of kV/m.

The equipment used in the experiment includes: ultra-wideband electromagnetic pulse radiation system, drone data link system, DC power supply, battery, attenuator, shielding room, shielding cavity, shielding catheter, oscilloscope, connecting cable and so on. The experimental instrument configuration diagram is shown in figure 1.

![Diagram of Experimental Instruments](image)

Figure 1 Schematic diagram of the connection of experimental instruments.

During the experiment, the UAV data link airborne end is placed in the UWB radiation field, the battery is used for power supply, and the battery is placed in the shielding cavity. The power cable is shielded by a shielded conduit. To avoid introducing interference through the power cord. The ground end is placed in the shielded box, and the ground end antenna is placed outside the shield to ensure that the drone data link can work normally. By adjusting the distance between the UAV and the UWB...
electromagnetic pulse source, the field strength around the UAV under test is changed. Adjustable attenuators are connected in series at the common port of the omnidirectional antenna of the data link system, adjust the attenuation multiple according to the flight distance requirement, and control the output signal strength to reach the "weak control" state, simulate the unmanned aircraft approaching the frontal position and the rear ground control. The communication status of the station. The experimenter can monitor the working changes of the UAV data link system under the electromagnetic pulse field irradiation through the on-board parameter display software. Divided into "locked" and "lost lock" status. "Locked" means that the drone data link system is working properly. "Lost lock" means the system is disturbed by electromagnetic pulses and cannot work or is damaged.

2.2 Experimental methods and experimental results

The irradiation experiment method is divided into the following steps:

1. Ultra-wideband electromagnetic pulse radiation system, UAV data link system, test equipment energized and preheated and reached a stable working state;

2. Verifying the relationship between the radiation field strength of the electromagnetic pulse radiation emission system and the distance, and the effective range of the pulse radiation field;

3. Because the experimental airborne data link equipment is well shielded, the housing has no heat dissipation holes, and only the front and back have wiring ports, so the test is carried out in two cases, one is irradiation the front end of the machine, and the other is irradiation the back end of the Airborne.

4. Adjust the peak voltage at the device under test by changing the value of \(x\), firstly carry out a single trigger effect test, observe the working state of the airborne data link system through link monitoring, and record the corresponding the value of \(x\);

5. Perform continuous triggering effect test on the airborne data link system, respectively control the trigger frequency and discharge voltage, and compare the influence of the two discharge parameters on the working state of the UAV data link system.

Through the UWB electromagnetic pulse test on the airborne end of the UAV, it is found that no matter the distance between the airborne end and the UWB radiation source, which part of the irradiator end, the single trigger will not lead to the UAV data link “lost lock” phenomenon; when the distance between the airborne end and the UWB radiation source is greater than 4m , the drone data link system will not lose lock when continuously triggered, only when the distance between the airborne end and the UWB radiation source is not greater than 4m (including 4m ), when the continuous trigger frequency is greater than 5Hz (including 5Hz ), the uplink data link system will be lost, and the uplink cannot be restored after the lock is lost, the machine data link channel cannot be changed, the corresponding UWB radiation intensity is 140 kV/m.

2.3 Loss of lock mechanism analysis

Since the energy of the ultra-wideband electromagnetic pulse in the experiment is mainly concentrated at the frequency of \(f_0\), and is relatively close to the operating frequency of the uplink of the UAV data link, the UWB electromagnetic pulse is easily coupled into the UAV receiving system via the front door, and creates interference to the uplink of the UAV data link.

The reason why the uplink cannot recover the locked state by itself is two reasons. One is that the transmitting signal of the ground control station is abnormal; the other is that the receiving signal is abnormal. Open the unmanned aerial vehicle transceiver combination airborne receiver, static monitoring is completed, the result shows normal; power-on detection, according to the debugging instructions, the test result is: when the signal source is -50dBm, the oscilloscope detects that the output signal sensitivity is normal, so the transmission signal can be excluded. The possibility of normal loss of lock can be inferred that the fault is caused by abnormal reception signal. The analysis should be caused by damage of a certain amplifier or automatic gain circuit fault. Test the working point of low noise amplifier, the first two outputs DC The operating point voltages are 0.3V and 0.9V, respectively, which are much smaller than the normal 6.2V and 9V. After troubleshooting, the fault is the damage of the first two stages of low noise amplifier in the front panel of the airborne receiver. After replacing the
low noise amplifier, the drone data link system returned to normal. Figure 2 is the circuit diagram of low noise amplifier.

![Circuit Diagram](image)

Figure 2 Low-noise amplifier circuit.

3. Analysis of UWB Electromagnetic Pulse Protection Method for UAV

3.1 Analysis of electromagnetic protection principle

According to the analysis of “lost lock”, the ultra-wideband electromagnetic pulse is mainly coupled into its RF front-end circuit through the unmanned aerial camera antenna. When the electromagnetic pulse propagates to the electromagnetic sensitive component inside the drone, the instantaneous power is much larger than the maximum input power that the device can withstand, which can cause the internal temperature of the device to rise sharply, causing fuse and stress damage, which leads to the drone data link. unable to work properly. Therefore, in order to reduce the ultra-wideband electromagnetic pulse energy coupled to the electromagnetic weak link inside the drone, from the perspective of the protection principle, the following two methods can be used to strengthen the electromagnetic protection of the drone: (1) reduce the antenna pair Coupling of electromagnetic pulse energy; (2) reducing the amplitude of electromagnetic pulse energy propagation to the front end of the radio frequency of the drone. The above two methods can be realized by adding various types of limiters and filters to the internal circuit of the drone, and considering that the pulse limiting power of various existing limiting devices is limited, it is easy to be subjected to high-power electromagnetic pulses. Damage, a single electromagnetic protection measure is not enough to adequately protect the electromagnetic weak points inside the drone. Therefore, it is necessary to comprehensively utilize the above various methods to comprehensively design the electromagnetic protection of the drone.

3.2 Electromagnetic protection method

3.2.1 Reduce the coupling of the antenna to the electromagnetic pulse:

For the method of reducing the coupling of the antenna to the ultra-wideband electromagnetic pulse, a method of installing an electromagnetic shield on the front end of the antenna of the drone can be used to spatially filter and spatially limit the ultra-wideband electromagnetic pulse before entering the antenna, thereby reducing The antenna couples the electromagnetic pulse to achieve the purpose of protecting the electromagnetic sensitive components of the front end of the radio. Frequency selective surface may be employed (FSS) as an antenna shield, a schematic view of the structure shown in figure 3.
Figure 3 Frequency selective surface structure sketch map.

The frequency selective surface is a two-dimensional or three-dimensional metal periodic structure, which can freely pass electromagnetic waves in the passband, and strongly reflect electromagnetic waves outside the passband. The selective coupling of the frequency selective surface can be utilized to reduce the coupling of the electromagnetic pulse energy to the antenna.

3.2.2 Reduce the amplitude of electromagnetic pulse energy propagation to the front end of the radio frequency of the drone:

The method of adding a filter and a limiter in front of the electromagnetic sensitive component inside the drone can be used to reduce the amplitude of the ultra-wideband electromagnetic pulse energy to the inside of the drone. The limiter is the key to the electromagnetic protection of the front end of the radio front of the drone. The main microwave limiters are: PIN limiter, gas plasma limiter, high speed microwave power switch, ferrite limiter, superconducting limiter, etc.

Among them, the PIN limiter is often used in the RF front-end to prevent the latter low-noise amplifier or mixer from being burned by high-power electromagnetic pulses. The most important device in the PIN limiter is the PIN diode, which is a diode consisting of a highly doped P+ region, an N+ region, and a lightly doped intrinsic I layer. When the tube is turned on, one end of the diode is grounded. When the applied electric field is relatively small, almost no carriers pass through the low-doped intrinsic layer for recombination. At this time, the normal working signal can completely pass through the limiter; when the high-power UWB electromagnetic pulse signal passes through the circuit, the PIN diode carriers traverse through the low-doped intrinsic layer to continuously recombine, and the UWB electromagnetic energy is discharged to the ground, thus playing the role of electromagnetic protection.

4. Conclusion

Through the analysis of the UWB electromagnetic pulse irradiation effect experiment on the UAV equipment, shows that the UAV data link is “lost lock” due to the damage of the low-noise amplifier of the sensitive device in the UAV’s internal circuit. At the same time, the experimental results also show that the ultra-wideband electromagnetic pulse is more harmful to the drone. Therefore, it is urgent to carry out research on electromagnetic protection of drones. Because the ultra-wideband electromagnetic pulse has the characteristics of fast rise time and large radiation power, it is difficult to fully and effectively protect the sensitive modules and devices of the drone with a single electromagnetic pulse protection method. Therefore, it is necessary to adopt multiple electromagnetic protection means at the same time. The integrated electromagnetic protection design of the machine to improve the survivability of the UAV equipment in the future complex battlefield electromagnetic environment.
References
[1] LIU S H, “The weaponry electromagnetic environment effects and its development trend,” J. Journal of the Academy of Equipment Command and Technology, 16(1), 2005, pp.1-6.
[2] GIRI D V and TESCHE F M, “Classification of intentional electromagnetic environments (IEME),” IEEE Transactions on Electromagnetic Compatibility, 46(3), 2004, pp.322-328.
[3] Zhang D X, Chen Y Z, and Tian Q M, “Lightning pulse magnetic field effects on UAV system,” J. High Power Laser and Particle Beams, 27, 2015, pp. 1032-36.
[4] Chen Y Z, Zhang D X, and Tian Q M, “HEMP Radiation Effects on Unmanned Aerial Vehicle Data Link System,” J. High Voltage Engineering, 42(3), 2016, pp. 956-965.
[5] ZHANG T, CHEN Y Z, TIAN Q M, and CHENG E W, “UWB Radiation Effects on UAV Data Link System,” J. High Voltage Apparatus, 49(8), 2013, pp. 21-25.
[6] LIU P G, LIU C X, and TAN J F, “Analysis of the research development on HPM/EMP protection,” J. Chinese Journal of Ship Research, 10(2), 2015, pp. 2-6.
[7] ZHENG S Q, DENG F, and WANG D D, “Overview of the HPM field-circuit integrated protection methods for electronic equipment and system RF-channels,” J. Chinese Journal of Ship Research, 10(2), 2015, pp. 7-14.