Research on electromagnetic radiation interference of high voltage pulse device

Xu Yuheng, Zhang Xiangjin, Wang Ruibo and Yue Lianyong

School of Mechanical Engineering, Nanjing University of Science and Technology, No. 200 Xiaolingwei Street, Xuanwu District, Nanjing, China
Xuyuheng1994@163.com

Abstract. In view of the strong electrostatic field interference caused by the miniaturization of high voltage pulse capacitor circuit, the protection method of electronic equipment under the strong electrostatic field interference of high voltage pulse device is proposed. Based on the background of miniaturization of all electronic security system, a high-voltage capacitor pulse discharge model is established. The surrounding radiation of high-voltage capacitor instantaneous discharge is simulated by using the COMSOL software. The electromagnetic radiation interference of high-voltage capacitor to the system is analyzed, and the anti-radiation interference measures are proposed based on the electromagnetic shielding mechanism. It provides a basis for the actual circuit design and structure layout, and provides a reference for the stability and safety of the electronic security system and further miniaturization development.

1. Introduction
The high voltage pulse discharge device is a system which uses the very insensitive characteristics of the exploding foil detonator to realize the safety control and initiation of initiating devices. In the process of the impact plate detonator, because of the large current generated by the internal metal bridge foil during the discharge of the high-voltage pulse capacitor, the electric explosion will drive the flyer to impact the insensitive explosive column and detonate it. In this process, the metal bridge foil needs to get enough energy to produce plasma in a short time, which requires that the output pulse current of high-voltage pulse power device can meet the requirements in amplitude and time characteristics[1]. With the electromagnetic environment becoming more and more complex, electromagnetic interference has become the main factor affecting the work of electronic equipment. Because of the characteristics of miniaturized ignition control system, it is very sensitive to electromagnetic interference, high-voltage switch and single-chip microcomputer and other components are easy to be damaged. The transient magnetic field strength is determined by $\frac{di}{dt}$[2]. According to the experimental results in the references, when the rise time is 10 ns, the pulse electric field with the peak value of kilovolt per meter can change the working state of the MCU and other controllers. In the high voltage pulse discharge device, the peak value of the transient current pulse of the pulse charging circuit is about 100 A, the rising time of the pulse is about 10 μs, and the intensity of the induced electric field is far lower than the critical value that can cause damage to the MCU, so the boosting process will lead to the damage of the single chip microcomputer[3]. It is necessary to analyze the electrostatic field generated in the discharge process of the high-voltage converter, and design the shielding measures.
2. Electromagnetic radiation interference principle of high voltage pulse device

2.1. Electromagnetic interference theory of high voltage capacitor

Generally, for initiation of impact plate detonators, the high-voltage pulse capacitor needs to reserve about 1300V high-frequency transformer for pulse boosting, convert the low voltage into high voltage and charge the capacitor through the high-voltage silicon stack until the detonation signal arrives, and the instantaneous discharge of the capacitor triggers the shock plate detonator. When the high-voltage converter is working, the capacitor will not discharge immediately after the charging reaches the predetermined target[4]. Therefore, the capacitor needs to maintain a high voltage of 1300V. The electrostatic field produced by the full charge of energy storage capacitor often makes the surrounding single chip microcomputer and other devices work abnormally or even damage[5].

The expression of electric field intensity of point charge q at any point b in space is as follows:

\[ \vec{E} = \frac{q}{4\pi\varepsilon_0 (r_a-r_b)^3} \vec{a}_R \]

\( \vec{a}_R \) is the unit vector from point b to point a.

The electric field intensity generated by the charge system at a certain point in space is equal to the vector sum of the electric field intensity generated at that point when each point of the charge system exists alone. Therefore, the electric field intensity of n-points charge to point “O” in s-plane is as follows:

\[ \vec{E} = \sum_{i=1}^{n} \frac{q_i}{4\pi\varepsilon_0 (r_0-r_i)^3} \vec{r}_i \]

\( \vec{r}_i \) is the distance vector of point charge \( q_i \) to O.

The voltage of o point generated by strong electrostatic field is:

\[ U = Ed \]

U is the potential difference, where d is the linear distance along the electric field line between two points. According to the principle of formula (1) and (2), when the energy storage capacitor of the electronic safety system is fully charged, a strong electrostatic field will be generated in the surrounding space.

The experimental results show that the strong static electric field is caused by the capacitance coupling between the devices with and without points. As shown in Figure 1, the voltage at both ends of the device is equal to the sum of the working voltage and the electrostatic field strength. The higher the voltage of the live device or the closer it is to the device, the more obvious the interference is[6].

![Figure 1. Schematic diagram of electric field intensity excited by space distribution point charge.](image)

2.2. Electromagnetic shielding principle

It can be seen from the above results that when the superposition voltage of the electrostatic field coupling at both ends of the device is too large and exceeds the withstand threshold of the device, the working state of the device will be disturbed. Therefore, to reduce the coupling voltage of electrostatic field as much as possible is an important condition to ensure the normal operation of MCU and other devices in the strong electrostatic field environment. When the device is placed near the side of the high-voltage plate, it will bear high voltage and cause damage to the device. Therefore, electromagnetic shielding measures should be taken. Shielding body can absorb energy, reflect energy and counteract
energy for external interference electromagnetic wave and internal electromagnetic wave from conductor, cable, component, circuit or system, so shielding body has the function of reducing interference. When the frequency of electromagnetic interference is high, the eddy current produced in low resistivity metal materials is used to counteract the external electromagnetic wave, so as to achieve the shielding effect \[7\]. When the frequency of the interference electromagnetic wave is low, the material with high permeability should be used, so that the magnetic field line is limited in the inner part of the shield to prevent diffusion to the shielding space. In the process of electromagnetic shielding, there are three main ways to attenuate the magnetic field: (1) Reflection loss of shield surface \( R_e \); (2) Absorption loss through shield A; (3) Multiple reflection loss in shielding body B.

Among them, the shielding effectiveness is quantitatively evaluated by \( SE \), 
\[
SE = R_e + A + B \tag{4}
\]
\[
R_e = 134.68 + 10 \log(\sigma_r f r^2 / \mu_r) \text{dB}
\]
\[
A = 131 h \sqrt{\mu_r \sigma_r} \text{dB}
\]
\[
B = 10 \log \left( \frac{1 + \exp(60.32 h \sqrt{\mu_r \sigma_r})}{-2\exp(30.16 h \sqrt{\mu_r \sigma_r}) \cos(30.16 h \sqrt{\mu_r \sigma_r})} \right) \text{dB}
\]
h is the thickness of the shield, \( \sigma_r \) is the relative conductivity, \( \mu_r \) is the relative permeability, \( f \) is the frequency, and \( r \) is the distance from the shield to the radiation source.

Table 1 shows the electrical properties of some metal materials.

| Material | \( \sigma_r / (S \cdot m^{-1}) \) | \( \mu_r \) | \( f/Hz \) | \( r/m \) |
|----------|-------------------------------|----------|-------|--------|
| 1045     | \( 5 \times 10^6 \)             | 150      | \( 10^3 \) | \( 10^{-3} \) |
| Iron     | \( 1 \times 10^7 \)             | 500      | \( 10^3 \) | \( 10^{-3} \) |
| Copper   | \( 5 \times 10^7 \)             | 1        | \( 10^3 \) | \( 10^{-3} \) |
| Aluminum | \( 3 \times 10^7 \)             | 1        | \( 10^3 \) | \( 10^{-3} \) |

3. Electromagnetic radiation modeling and simulation

The high voltage capacitor selected in this paper is multilayer chip ceramic capacitor (MLCC). Its main structure mainly includes three parts: ceramic medium, metal inner electrode and metal outer electrode. The multilayer chip ceramic capacitor is a multilayer composite structure, which is simply said to be a union of several simple parallel plate capacitors \[9\].

From the internal structure, it can be seen that MLCC capacitors are formed by alternately laminating and pressing multiple layers of ceramic dielectric films, which is a parallel form of multiple capacitors. The voltage drop between each layer of the film is small and non-polar. Therefore, in order to simplify the model structure when modeling, the influence of the strong magnetic field generated by the high voltage of the two-layer plates on the internal structure can be ignored. In this section, the MLCC capacitor actually used is equivalent to a two-layer planar structure for modeling and analysis.

Establish two planar plates in the space. The material of the planar plates is silver-palladium alloy, and the intermediate medium is ceramic. The two plates form a capacitor, and an air field is added.
around the capacitor. One of the plane plates is grounded, and the other plane plate voltage is 1300V. The model grid is shown in the Figure 3.

(Figure 3. Mesh map of storage capacitors.)

The calculation results are as follows. In order to facilitate analysis and comparison, considering that the shield model has a symmetrical type, take the central section and line segment a (from point (0,0,3.75) to point (0,0.6,5)) for observation.

(Figure 4 (a) is the spatial distribution map of the strong electrostatic field contour, Figure 4 (b) is the electrostatic field distribution map in the a’ direction, and the abscissa is the distance from the surface of the high voltage plate, as can be seen from the figure, The maximum electric field strength is in the direction of the axis of symmetry of the capacitor team, and the farther the electric field contour line diffuses outward, the smaller the potential value is, and the potential value is about 900V to 2.5mm from the high-voltage plate. It can be seen from the figure that when the semiconductor device is arranged along the axis of the high-voltage end, the potential difference to which it is subjected is the largest.)

4. Electric field shielding protection
Because this design is under the constraint of small volume, high-voltage capacitors cannot be independently arranged, and interference is easy to crosstalk through the cable between the boards. Also, the requirement of minimum volume and easy processing under the constraint of small volume, so consider using a thin-walled metal cylindrical shield, as shown in the figure. 6. Because the other side of the high-voltage capacitor is arranged as a pyrotechnic device, the device protection on the same side of the PCB is mainly considered in this design. The shield is a thin-walled cylindrical structure with a wall thickness of 0.5mm, and the material is defined as 1045 steel.
Add 1300V potential value to the high voltage plate, and ground the low voltage plate and the shield. It can be seen from the figure that the high-voltage region is concentrated inside the cavity of the shield and the surface of the inner cavity, and the electric field rapidly decays after passing through the cavity. The electric field attenuation is greatest along the negative direction of the Y-axis, that is, the direction in which the PCB is stacked. In order to visually show the change of the electric field, the spatial distribution of the electric field is analyzed from the horizontal and vertical tangent planes.

The above figure (a) is the contour map of the electrostatic field in the vertical tangent plane (XOZ plane). It can be seen that the shield has the best effect on the left space in the strong electrostatic field diagram because the shield is unidirectionally arranged. The field strength has been reduced to less than 5V at the center of the left 2mm away from the shield. Figure 2 is the distribution of the electric field strength in the direction of \( \vec{a} \). When the top of the plate passes through the cavity upward, the electric field...
field linearly decays and the amplitude is small. When passing through the shield case, due to the absorption effect of the metal, the electric field decays at a faster rate. When the upper surface of the shell decays to zero, the field strength gradually increases after the shell exits due to the diffusion of the electric field on the opposite side. The more the electric field is directly to the right, the stronger the field strength is, the maximum is about 50V. The change of the electric field at the bottom is the same as that of the top, but the field strength is lower than the top due to the direction of the low-voltage plate. The field strength directly below is about 8.125V.

![Figure 8. Contour distribution of the strong electrostatic field on the horizontal tangent plane.](image)

The figure above is the contour map of the strong electrostatic field on the plane horizontal tangent plane (XOY). It can be seen from the figure that the strong electric field is concentrated in the high voltage plate and the cavity of the shield.

From the above results, it can be seen that the copper shield can effectively shield the strong electrostatic field radiation generated when the high-voltage capacitor is discharged, and it can ensure that the single-chip computer used is not disturbed by the excessive coupling voltage in the strong electrostatic field.

5. Conclusion
This paper presents a method of single-chip microcomputer protection under the strong electrostatic field interference of a miniaturized pulse discharge device. The electrostatic field strength distribution and potential gradient in the three-dimensional space around the high-voltage energy storage capacitor of the electronic safety system were obtained through simulation calculations, and the structure of the shield was given based on the single-chip microcomputer's withstanding coupling voltage threshold. The simulation method used in this paper is generalizable. It can modify the model, loading voltage, boundary conditions, and material properties to meet the calculation of different electrostatic fields, and use COMSOL post-processor to extract various electrostatic field results for analysis. Due to the limitation of simulation conditions, the modeling and simulation process in this paper ignores the effects of circuit boards and other device materials on the electrostatic field in space, which inevitably differs from the actual situation. In the next, it is necessary to continue studying the electromagnetic radiation interference of high voltage pulse device.

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