Study on the Interaction between Channels of Image Intensifier

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Abstract: The experiment of mutual interference between channels of the UV imager was carried out. The platform consists of jamming light with large area and target light with small area was established. The curve of the gray value of target light in image intensifier with the intensity of interference light was measured. Experimental results show that there is mutual interference between channels when the UV imager is irradiated by continuous laser and the mutual effects will benefit to suppress the target signal by reducing the gain of the adjacent channels. Theoretical mechanism of this phenomenon was studied. The electrical coupling model between channels was established, and the influence of transverse resistance between adjacent channels on the gain characteristics of adjacent channels was studied by nodal analysis. Numerical simulation results show that the transverse resistance between channels is the main cause of mutual interference between channels, which greatly influence the gain of the adjacent channels.

1. Introduction

Ultraviolet imager has the characteristics of high gain, high temporal and spatial resolution. It is not only widely used in civil fields such as lunar base plasma detection[1], high-voltage corona discharge detection[2], but also has important military applications[3-4], as a core component of ultraviolet imaging warning device on aircraft and satellite platforms.

Laser has the characteristics of high peak and good directivity. It is a high brightness light source and very suitable for long-distance transmission. Laser interference and damage to optoelectronic imaging system has always been a research hotspot at home and abroad[5]. In 2007, RIC (H.) M. A. Schleijpen studied the relationship between different laser parameters and saturation area of infrared imaging system[6]. In 2010, Titterton D H and others analyzed the performance of four different interference evaluation indicators[7]. In 2011, Anne Dureuc studied the interference effect of laser with different parameters on HgCdTe focal plane array detector[8]. Domestically, in 2011, Zhang Zhen et al. interfered the TDI CCD with repetitive laser, and explained the phenomenon of equal interval black lines in images theoretically[9]. In 2012, Zhang Zhenyun et al. used the continuous laser to irradiate the linear array CCD, and studied the mechanism of three interference spots in the image[10]. In 2014, Kang Wenyun et al. used repetitive laser to interfere with push-broom camera, and compared it with staring camera[11]. In 2016, Shengliang et al. studied the phenomenon of pixel inversion when CMOS camera was irradiated by continuous laser, and explained the jamming mechanism[12]. It can be seen
that the research on laser interference and damage optoelectronic system mainly focuses on the interference and damage mechanism of CCD or infrared thermal imager, and the research on ultraviolet imager has not been reported publicly.

In this paper, we observed the gain saturation of MCP and the mutual interference between channels of ultraviolet imager while it was irradiated by continuous laser. The mechanism of channel interference was successfully explained by constructing a mutual interference model between MCP channels.

2. Experimental System

As shown in Figure 1, if the projection area of the ultraviolet tail flame of an incoming missile is small, the target can be seen as a strong point light source on the photocathode of a ultraviolet imager while it approaches the ultraviolet warning device from a long distance. At this time, the region of the image intensifier irradiated by the target is in a gain saturation state.

When the intensity of the interference light is weak and the projection area on the photocathode is much larger than that of the target light, the interference light wraps the target in the center of the field of view of the ultraviolet imager. Since the intensity of the interfering light is weaker than that of the target light, can the interfering light affect the imaging of the target light? To answer this question, the following experiments are designed.

![Figure 1 Projection distribution of target light and interference light on photocathode surface](image1)

![Figure 2 Schematic and physical diagrams of the experimental device for inter-channel interference](image2)

A: He-Ne Laser; B: Beam expander; C: Aperture; D: Splitter; E: Power meter; F: Image intensifier; G: Industrial camera; H: Attenuator; I: Deuterium lamp

Figure 2 Schematic and physical diagrams of the experimental device for inter-channel interference

The experimental device is shown in Fig. 2. It consists of two beams of light, one is the target light and the other is the interference light. The target light comes from a continuous He-Ne laser with a wavelength of 632.8 nm. A beam expander with magnification of 10 times and a small hole with diameter of 0.1 mm are placed in the target light path. The small hole is located behind the beam expander.
expander. The interference light source is a deuterium lamp, and its spot is large enough to fill all the field of view of the image intensifier. The neutral density filter is placed in front of the deuterium lamp, and the interference intensity is changed by adjusting the OD number of the filter. The lenses of the image intensifier are removed, and the image intensifier window is illuminated directly by the two light beams. The industrial camera is used to take the image intensifier fluorescent screen directly, and the image gray value represents the light intensity.

3. Experimental Results

Setting the integral time of CCD to 3.342 ms. When the power of the target light is $1.73 \times 10^{-10}$ W, the average power density of the target light at the photocathode plane of the image intensifier is $2.2 \times 10^{-6}$ W / cm$^2$, calculated from the spot diameter of 0.1 mm. At this time, the target spot is shown in Fig.3(a). It can be seen that the spot is circular distribution, and the maximum gray value of the spot center is 205. Fig.3(b) and Fig.3(c) are the imaging conditions of the image intensifier when the interference illumination is $1.1 \times 10^{-7}$ W / cm$^2$ and $4.4 \times 10^{-8}$ W / cm$^2$, respectively. When the interference illumination is $2.2 \times 10^{-6}$ W / cm$^2$, the corresponding gray value of the interference light is 45, and the corresponding gray value of the target light is 195. When the interference illumination is $8.8 \times 10^{-6}$ W / cm$^2$, the corresponding gray value of the interference light is 65, and the corresponding gray value of the target light is 137. It can be seen that the gray value of the target light decreases with the increase of the intensity of the interference light.

(a) The interference light intensity is 0 and the target light intensity is $2.2 \times 10^{-6}$ W / cm$^2$
(b) The interference light intensity is $2.2 \times 10^{-6}$ W / cm$^2$ and the target light intensity is $1.1 \times 10^{-7}$ W / cm$^2$
(c) The interference light intensity is $2.2 \times 10^{-6}$ W / cm$^2$ and the target light intensity is $8.8 \times 10^{-7}$ W / cm$^2$

Figure 3 Gray distribution of image intensifier under intense light irradiation

Figure 4 Changes of gray value of target spot with interference illumination

On the premise that the intensity of the interfering light is always weaker than that of the target light, the gray value of the target spot is obtained as shown in Fig.4 as the intensity of the interfering light is continuously improved. It can be seen that the gray value of the target light decreases continuously with the increase of the intensity of the interference light. It is assumed that the gain of the MCP channel corresponding to the target spot (hereinafter referred to as the activation channel) is affected by the surrounding channel (hereinafter referred to as the proximity channel). As the radiation intensity of the adjacent channel increases, the adjacent channel gradually enters gain saturation. The electrons originally supplied by the adjacent channel can not reach the activation channel in time,
resulting in the decrease of the gain of the activation channel. To verify this conjecture, the conduction mechanism of MCP is analyzed, and the current supplement model between MCP channels is established to study the effect of signal intensity of adjacent channels on the gain of activated channels.

4. Theoretical Analysis Model

The coupling between channels originates from the resistance connection between channels. In order to explain the coupling effect between channels, it is necessary to model the mutual coupling of current and potential between channels. The potential distribution in the channel is analyzed when different intensity signals are incident, and then the channel gain is determined by the potential distribution.

The two-channel coupling model is shown in Figure 5. Each channel is composed of \( n \) current sources and several resistance elements. Each element corresponds to the channel length of \( dz=L/n \), where \( L \) is the total length of the channel, and the current is the average value of the signal multiplier current in the channel in \( dz \). The signal current \( I_{in} \) enters the channel at the channel entrance \( z=0 \), and \( I_{o} \) is the output current at the channel exit \( z=L \). The potential difference between the entrance and the exit is \( U_0 \).

The boundary of the resistance unit in the equivalent circuit is the insulation layer around the channel: the transverse resistance \( R_1 \) is the resistance between the emitter layer resistance and the conductive layer, the longitudinal resistance \( R_2 \) is the channel conductive layer resistance, and the transverse resistance \( R_3 \) is the coupling resistance between the channels. In this figure, the magnitude of the element resistance is: \( r_1=R_1(n-1) \), \( r_2=R_2/n \), \( r_3=R_3(n-1) \).

![Figure 5 Equivalent circuit diagram of resistance coupling between two channels](image)

Literature [13] has elaborated the method for calculating the current gain of single channel under saturated and unsaturated conditions. Based on the above theory, the channel electric field distribution under uncoupled conditions can be solved. The current and potential distribution in the channel can be solved by the iterative method in the case of coupling. The steps are as follows:

1. Based on the circuit analysis theory, the voltage distribution of each node of the equivalent circuit is calculated according to the current distribution \( I_i \) and \( J_i \) in the channel. \( u_{i,n} \) is taken as the solution object, which contains a total of \( 4(n-1) \) unknowns. \( u_{i,n}=V_s \) is known. By using node analysis method [14], a total of \( 4(n-1) \) independent equations can be obtained for each node in the circuit, which can be used to solve the potential value of each node in the circuit.

2. Based on the voltage distribution calculating method, the current distribution in the channel can be obtained. The current gain of each cell in the channel is related to the potential difference at both ends of the cell. The multiplied current value of each cell in the channel can be solved by the following formula.
\[
I_i = I_{in} \exp \left( \frac{i}{n} M_0 \right) \exp \left( \sum_{j=0}^{n} \ln \left( 1 + \frac{d \Phi(i)}{v_i} \right) \right)
\]

(1)

In the formula, \( M_0 \) is the gain under unsaturated condition and \( \Phi(z) \) is the channel voltage and offset \( \Phi(z) = u_i - v_i \).

In the first iteration, the current distribution in the channel under unsaturated conditions can be simulated. When unsaturated, the channel potential distributes uniformly along the axis. From the formula (1), the channel current increases exponentially along the axis.

The coupling model between channels and the calculation method of the input and output currents of each channel under the coupling condition are given above. An example of the effect of the coupling between channels on the imaging process of image intensifier is given below.

5. Result Analysis

The parameters of the microchannel board are set as Table 1.

| Parameter                  | Value   | Unit  |
|----------------------------|---------|-------|
| Channel length \( L \)     | 320     | μm    |
| Pore diameter \( d_c \)    | 5       | μm    |
| Center to center distance \( h \) | 6  | μm    |
| \( R_1 \)                  | 8×10^{10} | Ω     |
| \( R_2 \)                  | 8×10^{15} | Ω     |
| Emission layer thickness   | 0.01    | μm    |
| Resistive layer thickness  | 0.2     | μm    |

The transverse resistance \( R_3 \) between channels depends on the conductivity of the channel material and can be calculated by the following formula:\[15]\:

\[
R_3 = \frac{\rho}{L} \left[ \frac{2h}{\sqrt{h^2 - d_c^2}} \arctan \left( \frac{h + d_c}{h - d_c} - \frac{\pi}{2} \right) \right]^{-1}
\]

(2)

The longitudinal resistance \( R_4 \) between channels can be calculated by the following formula:

\[
R_4 = \rho L \left( d_c h - 0.25 \pi d_c^2 \right)
\]

(3)

In the formula, \( \rho \) is the resistivity, which is substituted with the parameters of microchannel board. \( R_3 \approx 8.25 \rho \Omega \) and \( R_4 \approx 3.2 \times 10^5 \rho \Omega \) can be obtained. The unit of \( \rho \) is \( \Omega \cdot \text{cm} \). From the analysis of the structure of microchannel plate, each channel is resistive shunt with resistance value \( 2R_4 \). Assuming that the shunt current does not exceed \( 3% \) of the channel current, \( 2R_4 \geq 20R_2 \) is required. Substituting (3), you can get: \( \rho \geq 2.5 \times 10^1 \Omega \cdot \text{cm}, R_3 \geq 2 \times 10^7 \Omega \).

Figure 6 illustrates the relationship between channel gain and resistance \( R_3 \) in the case of two channels. The two groups of curves in the figure are weak saturation state \( I_{in} = 2J_{in} = 2 \times 10^{-6} \text{A} \) and strong saturation state \( I_{in} = 2J_{in} = 2 \times 10^{-16} \text{A} \) respectively. It can be seen that when \( R_3 \geq 2 \times 10^7 \Omega \), the gain of channels is independent of \( R_3 \), and there is no coupling between channels. As the coupling resistance decreases, the coupling between channels becomes stronger and stronger. The gain of large
signal channel is increased while that of small signal channel is decreased, and the gain of two channels is closer.

Figure 6 The relationship between channel gain and coupling resistance,

\[ I_{in} = 2J_{in} = 2 \times 10^{-17} \, \text{A}, \quad 2 - I_{in} = 2J_{in} = 10^{-16} \, \text{A} \]

Figure 7 Electric field distribution in the channel: solid line- $R_3 = 2 \times 10^{17} \, \Omega$, dotted line- $R_3 = 2 \times 10^{12} \, \Omega$

Fig. 7 shows the electric field distribution in uncoupled ($R_3 = 2 \times 10^{17} \, \Omega$) and strongly coupled ($R_3 = 2 \times 10^{12} \, \Omega$) channels when $I_{in} = 2J_{in} = 10^{-16} \, \text{A}$. In the case of strong coupling, the maximum difference between the electric fields of the two channels is less than 3% because the longitudinal resistance $r_2$ in the channel is connected by the virtual resistance $r_3$, which indicates that the potential and electric field distribution in the two channels tend to be the same in the case of coupling.

The above results show that the transverse resistance between channels has a great influence on the channel gain.

6. Conclusion
Starting from the experimental phenomena, the ultraviolet imager is irradiated by continuous laser. The imaging characteristics of ultraviolet imager before and after irradiation are compared and analyzed. The gain saturation phenomenon of ultraviolet imager and the mechanism of channel interference are studied.

Channel interference results from the electrical coupling between channels of microchannel plate while ultraviolet imager irradiated by CW laser. The electrical coupling between channels helps to reduce the gain difference between channels and the effect of gain saturation on image quality. The coupling resistance improves the image quality obviously. Within the permissible range, the distributing resistance between MCP channels can be minimized, which is beneficial to improve the contrast transfer ability of microchannel plates.
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