# Test and analysis of the halo in low-light-level image intensifiers

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A halo tester is designed to analyze the halo formation in low-light-level (LLL) image intensifiers and the influencing factors on halo size. The tester is used to collect a 0.1922-mm hole image directly using a CoolSNAP$_{K4}$ charge-coupled device (CCD) in a darkroom under illumination conditions between $10^{-2}$ and $10^{-4}$ lx. The practical measurement result shows that the amplification ratio is 343.4. Then, the super second- and third-generation image intensifiers are placed after the hole, and the halo sizes of the hole images on the screens are determined as 0.2388 and 0.5533 mm, respectively.

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The International Telephone & Telegraph (ITT) Corporation offers the third-generation (Gen III) image intensifiers of the F9800 (MX-10160) and the F9815 (MX-11769) series. These tubes include ITT's Pinnacle® technology, which surpasses the performance of all other previous and current Gen III tubes in the field. Each model in these Gen III 18-mm image intensifier tube series consists of a highly efficient GaAs photocathode bonded to a glass input window, a microchannel-plate (MCP) current amplifier, and a P-43 phosphor screen deposited into an inverting fiber-optic output window. ITT has reported the performance parameters of these Gen III 18-mm image intensifiers. According to ITT's tube halo effect test, the input light spot diameter is 0.35 mm. The minimum resolutions for the F9800 and the F9815 series tubes are both 64 lp/mm. The maximum halo size for the F9800 series tubes is between 0.70 and 1.25 mm, and that for the F9815 ones is between 1.00 and 1.25 mm[1]. For the super second-generation (Gen II+) image intensifiers produced by PHOTONIS Corporation, the minimum resolution is between 45 and 64 lp/mm, and the maximum halo size, without the input light spot diameter, is between 0.8 and 1.0 mm[2]. PHOTONIS Corporation has conducted an experiment in the same environment observed with different night vision systems. The halo sizes are typically 0.8 and 2.0 mm for XR5™ and Gen III, respectively[3].

For the proximity focusing system of the low-light-level (LLL) image intensifiers, the pre- and post-proximity distances both determine the halo size. The shorter the distance, the smaller the halo size. A halo is not an important performance parameter for image intensifiers[4−7], but it indirectly affects the resolution and signal-to-noise ratio (SNR). Recently, studies on the halo size for LLL image intensifiers are scarce. Although foreign researchers have reported the halo size for different tubes, the halo sizes of domestic image intensifiers have not been studied. Thus, a halo tester was designed to analyze the formation mechanism and influencing factors of the halo on the image intensifier screen. The images of a 0.1922-mm hole on the Gen II+ and Gen III image intensifier screens were collected using a CoolSNAP$_{K4}$ charge-coupled device (CCD).

As stated earlier, the image intensifiers consist of a photocathode, a MCP, and a phosphor screen[8,9]. When a bright light spot of a certain size is viewed through LLL image intensifiers, the image of the input light spot on the phosphor screen can appear as a "halo" that is much larger than the "weak-signal" point spread function of the image intensifiers[10].

After a small light spot irradiating the photocathode of image intensifiers, the halo effect of image intensifiers is tested and the halo image is collected using a high-resolution CCD. The small input light spot diameter is usually between 0.1 and 0.4 mm, and the light spot can be obtained using a projection lens or an aperture. In this letter, the small light spot is obtained using an aperture because the photocathode surface of the tested image intensifier in the experiment is flat. The halo tester includes a light source, filters, an integrating sphere, a small hole, a photoelectric detector, a light-tight box, a magnifier lens, a CoolSNAP$_{K4}$ CCD, and a mechanism, as shown in Fig. 1.

The light-source component consists of a light source, filters, an integrating sphere, and a small hole. The light source is the OSPAM halogen lamp, whose working voltage and power are 6 V and 10 W, respectively. The light-source component should produce a uniform light spot with a certain illumination to prevent saturation when the CCD collects the halo image on the image intensifier screen. The integrating sphere insures that the input light spot is uniform. The light spot illumination

 

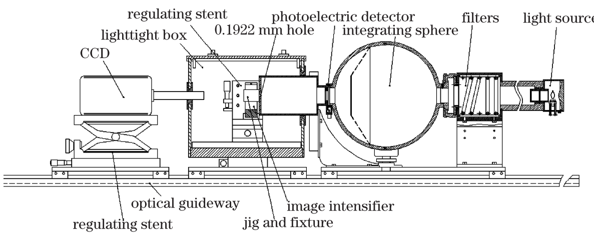


Fig. 1. Schematic diagram of the halo tester structure.

can be regulated using the filters and the aperture at the entrance of the integrating sphere and is monitored by the photoelectric detector. The light spot illumination can be controlled between $10^{-2}$ and $10^{-4}$ lx using the NEKO1S filters produced by THORLABS Corporation. The size of the input light spot is determined by the small hole. The image acquisition system consists of the camera lens and the CoolSNAP$_{\mathrm{K4}}$ CCD. The CCD is an industry-leading camera for low-light fluorescence microscopy. The resolution of the CoolSNAP$_{\mathrm{K4}}$ CCD is $2\,048\times2\,048$ pixels, and its sampling frequency is 20 MHz. The frame speed is 3 fps, and the dark current is 0.1 e-/p/s. The exposure dose on the CCD photosensitive surface should be lower than the saturated exposure dose to avoid light saturation and cross talk during image collection.

The abovementioned modules were all assembled, and the OSPAM halogen lamp and the image intensifier were placed in the tester, as shown in Fig. 1. The position of the image intensifier was adjusted and fixed to align the image intensifier with the hole. The filters were then inserted into the tester to diffract the light. Through the integrating sphere and the 0.1922-mm hole, the light from the halogen lamp became a uniform and low light spot. Photoelectric conversion, electron multiplication, and electro-optical conversion were realized using the image intensifier. The optical signals were converted into electric signals using the CoolSNAP$_{\mathrm{K4}}$ CCD, and the electric signals were converted into digital signals using an analog-to-digital converter. The digital signals were fed into the computer after compression and then saved into a flash memory or into the hard disk card of a camera. Finally, the collected images were shown on a computer monitor.

The halo image for an input light spot that does not pass through the image intensifier was firstly collected to analyze the influence of the image intensifier on the halo image collected by the halo tester. In the halo tester, the straight pipe with a 0.1922-mm hole was substituted with the conjugated symmetric lens behind the integrating sphere, and then, the 0.1922-mm input light spot was obtained. The 0.1922-mm hole was produced via lithography and etching technologies. The halo image for the input light spot was directly collected using the CoolSNAP$_{\mathrm{K4}}$ CCD in the darkroom and saved in bmp format, as shown in Fig. 2. During the lithography and etching processes, the defect and error led to some notches in the halo image edge. However, these notches could be ignored during the halo size measurement. Then, the halo image was opened in a computer using a drawing tool. The halo size for the 0.1922-mm input light spot is 66 mm. Thus, the amplification ratio of the halo tester is $66/0.1922 = 343.4$.

Then, the halo images on the image intensifier screen were collected. The conjugated symmetric lens behind the integrating sphere was appended, and the image intensifier was placed in the light-tight box. After the light spot irradiating the Gen II+ and the Gen III image intensifiers, respectively, the halo images on the image intensifier screens were collected using the CCD, as shown in Fig. 3. Following the aforementioned measuring method, the halo sizes were determined as 82 and 190 mm for the Gen II+ and Gen III image intensifiers, respectively. The halo sizes were divided by the amplification ratio, and the practical halo sizes were obtained as 0.2388 and 0.5533 mm, respectively. The results show that the halo size for the Gen II+ image intensifier is smaller than that for the Gen III.

Figure 3 shows an aureole around the central bright spot, which is the collected image for the 0.1922-mm hole on the image intensifier screens. The photoelectrons escape from the photocathode into the MCP input face because of the effect of the accelerating field in the proximity focusing system. Some electrons enter the MCP channel pore, whereas others collide with the MCP non-opening face, leading to the scattering of electrons on the MCP input face, as shown in Fig. 4. Then, the scattering electrons may enter the channel pore or collide with the MCP non-opening face again because of the accelerating field. Through the photomultiplier, the scattering electrons entering the channel pore bombard the phosphor, causing serious noise. The symmetric angle spread of the escaped photoelectrons forms an aureole around the central bright spot in the halo image.

For the analysis of the halo formation mechanism and the influence of the Gen II+ and Gen III image intensifiers on the halo image, the brightness values of all

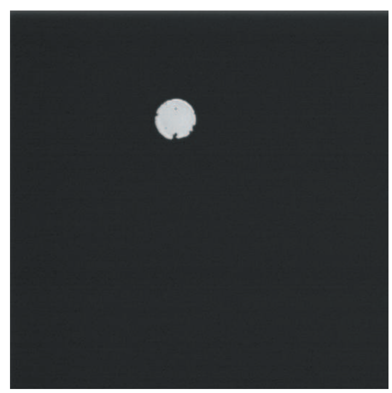

Fig. 2. Halo image for the 0.1922-mm input light spot collected by CCD.

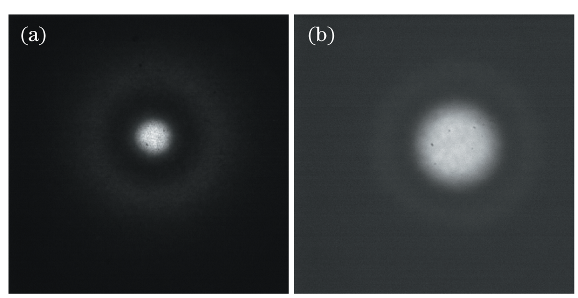


Fig. 3. Halo images on the LLL (a) Gen II+ and (b) Gen III image intensifier screens collected by CCD.

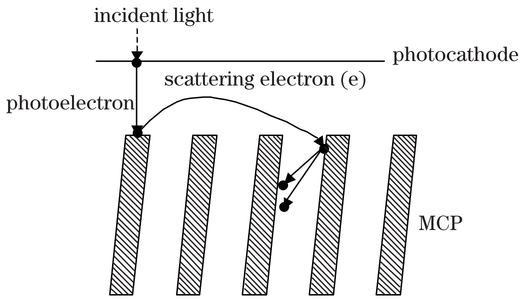


Fig. 4. Schematic diagram of the electron scattering on the MCP input face.

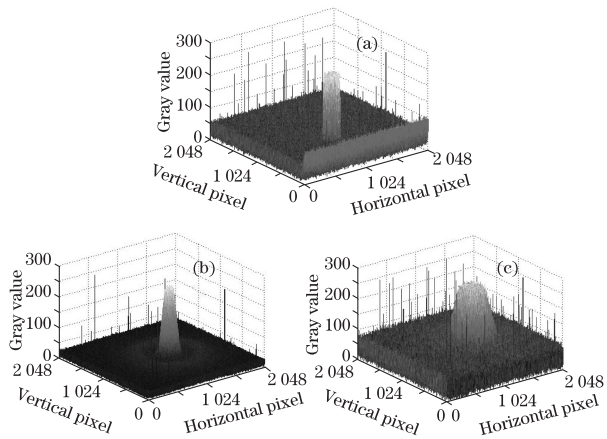


Fig. 5. Gray value distributions of the halo images. (a) 0.1922-mm input light spot, and (b) Gen II+ and (c) Gen III image intensifiers.

collected images were transformed into gray values, as shown in Fig. 5. In the halo image for the input light spot, the gray value distribution was basically uniform. For the halo images on the Gen II+ and the Gen III image intensifier screens, the center gray values were both high and the gray values around the center were both low. The gray value distributions for the Gen II+ and the Gen III image intensifiers were paraboloidal.

According to the working principles of the LLL image intensifier and the CCD, the formation of the halo image collected by the CCD can be described as shown in Fig. 6. The halo image on the image intensifier screen contains much useful information and unnecessary noise. The useful information includes the parameter values of the photocathode, MCP, and phosphor screen. For instance, the closer the MCP is to the photocathode, the smaller the halo size. The noise in the halo image includes the noises of the photocathode, MCP, phosphor screen, and CCD during the working process. For example, the image intensifier noise reduces as the scattering electrons on the MCP input face decrease with the use

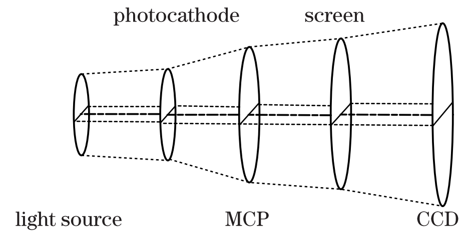


Fig. 6. Schematic diagram of the formation mechanism of halo images.

of flaring technology.

In conclusion, the halo size for the Gen II+ image intensifier is smaller than that for the Gen III one. The velocities of the electrons escaping from the photocathode are different. Thus, inevitably, the electrons move in the lateral direction, leading to a dispersion circle on the MCP input face. Moreover, an aureole is formed around the central bright spot on the image intensifier screen because of the scattering electrons on the MCP input face. Considering that the parameter value that plays an important role on the halo size is unknown, the halo image should further be analyzed. Thus, the next work will focus on the analysis of the halo formation mechanism and is expected to provide an effective way to improve the SNR ratio or the resolution of the LLL image intensifier.

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