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Research on laser photoelectricity detection performance and equivalent noise calculation method of detection circuit in laser detection system

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Laser detection system is greatly influenced by sky background illumination and reflection characteristics of the target, to improve the detection performance of laser photoelectricity detection optical system; this paper studies the laser photoelectricity detection performance and the calculation method of equivalent noise of detection circuit. Based on laser detection principle, the relation between target reflection radiation flux and the background illumination are analyzed and the calculation model is established. The calculation function of target reflection surface area is deduced by using finite element analysis method which divides the target surface area into a lot of unit areas, the calculation method of the reflection laser energy that the photoelectric detector can receive is analyzed, and the mathematical function about detection distance and laser illumination is obtained. Based on the detection circuit, the calculation method of detection circuit equivalent noise is set up and the expression on SNR is deduced. Through experiment and analysis, the relation between the detection distance and laser luminous flux and SNR are found, at the same time, the results show that the SNR is higher and the laser power are stronger, the reflected laser is stronger in detector, and the target reflector area is greater, the detection sensitivity is higher.

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1. Introduction

At present, there are many publications dedicate to research detection performance in photoelectricity detection field, and for different detection systems, there are different ways to improve the detection performance. With electromagnetic detection, millimeter wave and infrared detection widely used, and the detection ability of detection system has been the focus [1]. Therefore, how to improve the performance of detection system has become a hot scientific issue to be resolved. There are many ways to improve the detection capability: based on the analysis about the detector output noise, some references had built an equivalent model, and chosen a suitable detector to improve detection ability[2-4]; studied the pre-detection circuit and showed a method to improve the detecting ability of the detection system[5]; proposed advance the optical field to better the detection performance; studied the reflection characteristics of the target, and found the factors which affect the reflection of the target, by improving the reflection characteristics of the target, the detection performance of the detection system could be better[6-7]; the reference [8] researched the interference from sky background radiation, got the method of reducing interference and improving the anti-interference ability of the detection system. However, there is no one to study more factors which impact the detection performance of detection system, from which, the detection performance of the detection system could be improved, significantly, at the same time, most of those studies just analyzed and discussed the detection performance in theory, but the productions that they have got in their studies have not been effectively verified by experiment or practice. The detection performance can be improved by advancing the SNR of the detection system, which is based on the analysis of the factors that influence the detection capability of detection system. Therefore, laser field and the photoelectric detection circuit are taken as a whole, and Bidirectional Reflectance Distribution Function and finite element analysis are introduced, the transfer function of laser propagation field and the equivalent noise calculation medal of detection circuit are set up; the factors influencing the SNR and detection performance of detection system are derived and analyzed.

2. The calculation on sky background radiation and laser propagation

2.1. The analysis and calculation on sky background radiation

To a detector, any subject that emits light or heat is likely to be a radiation source. In reality, the detector can receive radiation from sky background, sun and reflected radiation which from the earth and the atmosphere [7]. In the detection system working condition, the radiation from sky background has a remarkable influence than other factors on detection performance, so the sky background is selected as the primary radiation source. In order to analyze the influence that radiation flux from sky background on the detection system, the value of radiation flux from sky background needs to be calculated.

In infrared laser detection system, the detector only responses to a certain wavelength which in the infrared spectrum, therefore, the specific infrared spectrum which exist in sky background are considered. Assuming that the radiation flux from background is Φ_d, it is a function which is relate to the wavelength λ. Based on the optic theory, Φ_d can be given by

$$\Phi_d = \int_{\lambda_1}^{\lambda_2} \partial(\lambda) S(\lambda) d_\lambda \tag{1}$$

Here λ_1 and λ_2 are the minimum and maximum wavelength, respectively, which can be detected by detector, $\partial(\lambda)$ is a wave scattering coefficient that infrared spectrum on atmosphere, $S(\lambda)$ is the atmosphere infrared luminous flux. Based on the theory of Mie, when the atmosphere thick is H, in the unit area, the scattering coefficient can be written as follows:

$$\partial(\lambda) = \frac{32\pi^3(\varsigma - 1)^2}{3N\lambda^4} \times H \tag{2}$$

Where ς is the average refractive index, and N is the number of scattering particle for per unit volume.

Suppose, the background luminance in the receiving optical lens is L_d *(cd/m²)*, and then substitute the parameters of the detection system into Eq. (1), the radiation flux on the pupil generated by the sky background can be expressed by formula (3)

$$\Phi_d = \frac{\pi^2 D^2 d^2 \tau}{16 f^2} \times L_d \tag{3}$$

In Eq. (3), d is the diameter size of the photoelectric detector. τ is the light loss in atmosphere [8-10]. Since the laser transmittance is limited by lens material, the radiation flux on the pupil generated by the sky background has a certain loss, and the rest of the radiation flux is all received by the detector. Setting τ_1 is the transmittance of the receiving lens, and then the illumination in the detector photosensitive surface caused by sky background can be given by

$$E_d = \frac{\pi\tau\tau_1}{4} \times (\frac{D}{f})^2 \times L_d \tag{4}$$

When the area of the detector photosensitive surface is S_1, according to the relationship between luminous flux and illumination, the luminous flux that the detector receives from the sky background can be expressed by

$$\Phi_1 = \int E_d dS = \frac{\pi\tau\tau_1}{4} \times (\frac{D}{f})^2 \times L_d \times S_1 \tag{5}$$

2.2. The calculation on the target reflection laser in the photoelectric detector

In laser detection system, when the spherical target is exposed to the laser completely, supposing the luminance of the laser is L (cd/m^2), the laser irradiates to the target vertically, the propagation distance is R *(m)*, and the radius of the spherical target is r *(m)*. Reflected by the spherical target surface, some laser arrives in the receiving lens. Since the target surface is curved, the laser reflected from the target can be calculated by finite element analysis.

$$W = \sum_{i=1}^{n} C_i N_i \tag{6}$$

Where C_i is the undetermined coefficient, N_i is a linear basis function. According to the theory of finite element analysis and the formula (6), the spherical target which irradiated by laser can be divided into many no overlapping reflection unit areas. Firstly, the laser energy reflected from the one unit area of spherical target which radiated by laser should be calculated, and then by summing the laser energy reflected from all the unit areas, the total laser energy reflected from the target can be got.

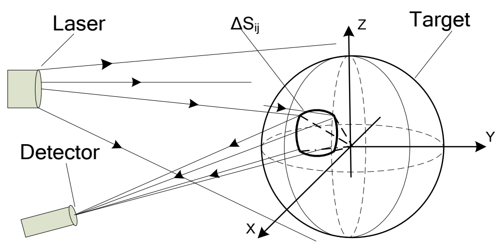


Fig. 1. The schematic diagram of reflected laser by the target's unit area ΔS_{ij}.

As Fig. 1, When the laser is working, ΔS_{ij}, one of the target's reflection unit areas, reflects the laser ,and then the reflected laser could be received by detector.

When ΔS_{ij} is irradiated by the laser whose luminance is *L*, taking fully into account the laser loss during transmission, the illumination function at the target can be expressed as:

$$E_T = \frac{e^{-\varepsilon R} \times \iint_{\Sigma} L\ d\Omega dS}{\pi r^2} \tag{7}$$

In formula (7), ε is the attenuation coefficient that laser to atmosphere.

In reality, the characteristic of the target reflection is a directional reflection, and the process of the reflection is complicated, it is different with mirror reflection and diffuse reflection. The reflection is related to the characteristics of target material, and the calculation about reflected laser could not be dealt with a target reflection coefficient [11-12]. For those reasons, the Bidirectional Reflectance Distribution Function is employed instead of target reflection coefficient to analyze the processing of reflection [13], and the function is expressed with ρ_b, it is given by

$$\rho_b = \frac{A}{\cos^6 \alpha} \times \exp[\frac{-\tan^2 \alpha}{\chi^2}] + B \times \cos^n \alpha \tag{8}$$

In (8), α is the laser incident angle in the target, its scope is $(-\pi/2, \pi/2)$. *A* and *B* is the amplitude coefficient, χ is the slope mean square of the material on the surface, *n* is a index, the greater the n is, the higher the index peak is. Considering the fact that laser could be absorbed by the lens material, and assuming the absorption is τ_2. When the target receives the laser signal, the relationship between luminance and illumination in ΔS_{ij} can be expressed as:

$$L_0 = \int_{\varphi_1}^{\varphi_2} \rho_b \times E_T (1 - \tau_2) d\alpha \tag{9}$$

Since the distance between the laser and the receiving lens is short in experiment, the relation adheres to the condition that $R >> l$. Thus, it can be considered that the receiving lens and laser are on the same geometry. The illumination in the pupil caused by the ΔS_{ij} reflected laser can be described as follows:

$$E_0 = \pi \times L_0 \times \frac{r^2}{R^2} \times e^{-2\varepsilon R} \tag{10}$$

Because the detector is small, the laser signal it could receive is very weak, in order to get more reflected laser signal, it is necessary to set a lens in front of the detector, and thus the detector can receive more laser. Assuming the laser illumination near the detector photosensitive surface is E_1. The focal length for the receiving lens is *f*, and the diameter is *D*, the distance between lens and image is d_1. According to the principle of optical imaging, the Fig. 2 is got.

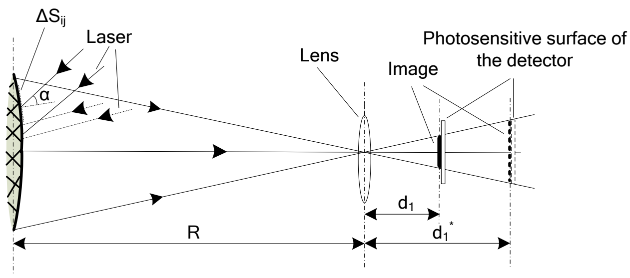


Fig. 2. Imaging principle of the ΔS_{ij}.

Assuming that the target detection effective surface area is ΔS_{ij}, and the image area of ΔS_{ij} in the detector is S_2, they comply with the following relationship

$$S_2 = (\frac{d_1}{R})^2 \times \Delta S_{ij} \tag{11}$$

And then we could get the laser radiation flux, which is reflected by ΔS_{ij}, received by the detector is for

$$\Phi_{ij} = \int E_1 dS = \tau_1 E_0 \times \frac{d_1^2}{R^2} \times \Delta S_{ij} \tag{12}$$

According to the formula (6), when Φ_{ij} is got, the total laser radiation flux, which are caused by all the target's reflection unit areas can given by

$$\Phi_1 = \sum \Phi_{ij}$$

$$= \tau_1 E_0 \times \frac{d_1^2}{R^2} \times \iint \Delta S_{ij} dS$$

$$= \tau_1 E_0 \times \frac{d_1^2}{R^2} \times S_0 \tag{13}$$

Here, S_0 is the effective reflection area of spherical target.

On the basis of those studies, the more reflected laser energy could be received by improving the factors which impact the reflected laser energy. Because the laser device is the source of laser illumination, and also the reflected laser, to improve the amount of the reflected laser, the laser power should be increased. Since in the process of laser transmission, the laser could be attenuated by atmosphere, especially in wet and no-pure condition, to increase the reflected laser energy, the condition should be pure and dry which is good for the laser transmission. For different material target, they have a different absorption for laser, to get more laser energy in detector; the absorption should be as little as possible. According to the target reflection characteristic, plane and smooth target could reflect more laser energy, so it is necessary to make the target planer and smoother, if we want to get more laser energy in detector.

The reflected laser energy is significantly influenced by the optical path, to improve the target reflected laser from the point of optical path, a comprehensive analysis is conducted based on Fig. 1, Fig. 2, Fig. 7(in Simulation and experiment part), formula (8) and the formula (11). Firstly, there is a relation between laser incident angle α and reflected laser energy, little the incident angle α is, the stronger the reflected laser energy, to get more reflected laser, the incident angle α should be small. Secondly, the receiving lens is an important factor which need to be considered, for it deicide how much laser which reflected by target could be received, to get more laser energy, the radius of the receiving lens should be large. By those measures, more laser energy could be got in detector. Because in the real condition, laser sensitive area of the detector is limited, therefore, in order to make the image of target is fully made in the surface of the detector, d_1 should be controlled as a certain distance, which signifies to get more reflected laser in the detector, when the diameter of the photosensitive surface of the detector is d , the perfect distance between lens and image can be expressed by

$$d_1^* = \frac{R \times d}{2r} \tag{14}$$

So, when the detect distance is constant and d_1 is d_1^*, greatest laser energy could be got. Based on this theory, the best optical path for the most laser energy is as shown in Fig.2, the dotted line that stands for the best laser optical path which has a little incident angle α in the target, d_1^* stands for the best distance between lens and image.

Based on formula (10) and (13), the relationship between the detection distance and laser illumination can be described as formula (15),

$$\frac{R^4}{e^{-2\varepsilon R}} = \frac{\pi L_0 r^2 \tau_1 d_1^2 S_0}{\Phi_1} \tag{15}$$

Neglecting some inferior factors which impact the detection distance, the function about detection distance and factors which significant affect the detection distance can be expressed as follow,

$$R = F(L_0, S_0, \varepsilon, r, \tau_1, d_1, \alpha, \chi) \tag{16}$$

Based on formula (15) and formula (16), the relation between detection distance and factors which impact the detection distance is got. When laser illumination is L_0, it has a significant effect on the detection distance, if it is enlarged, the detection distance could be longer, and for effective reflection area of spherical target is S_0, it decide how much of the laser energy could be reflected from the target to detector, and also it could impact the detection distance, to increase S_0,the detection performance could be improved, and τ , r , d_1 will play an positive role in the detection performance, if they could be large. However, ε , α , χ would diminish the detection performance, if the value of them is large, and they are hoped little in experiment. According to the formula (15), when the laser illumination L_0 is got, the detection distance could be got.

The radiation flux that the detector could receive, which caused by sky background and the reflected laser from target are got, in order to contrast the relative radiation intensity of the sky background and the reflected laser, P is introduced, which is defined as the ratio of relative intensity of laser radiation and sky background radiation near the detector, it is given by

$$\mathrm{P} = \frac{\Phi_1}{\Phi_0} = \frac{4E_0 S_0 f^2 d_1^2}{\pi \tau_1 L_d S_1 D^2 R^2} \tag{17}$$

In (17), it shows that when the value of P is measured, then the relative radiation intensity of the laser reflected from target and the sky background could be got. P could be raised by enlarging f and E_0, or reducing D and so on.

When the photoelectric detector receives the laser signal, the detector could transform photon signal into electron signal, and the relationship between the current and the laser radiation flux can be expressed as:

$$i_p = \frac{e\eta}{h\nu} \times \Phi_0 \tag{18}$$

The current i_d caused by sky background radiation flux as follows:

$$i_d = \frac{e\eta}{h\nu} \times \Phi_1 \tag{19}$$

Where e is the electron charge, η is the quantum efficiency, h is the Planck Constance and ν is the light frequency [14]. When i_p and i_d are got, the detection performance could be studied further from the point of detection circuit.

3. Equivalent noise's modeling of the detection circuit

Given the working condition, laser, target and receiving optical structure of the detection system, to improve the detection performance of the detection system further, the noise characteristics of the detector circuit should be studied. By studying the noise, a characteristic about high Signal to Noise Ratio (SNR) of the detection system is obtained, and the method to improve the detection performance is developed. Because the size of the receiving lens is limited in the detection system, the laser power in the pupil is small, and thus the electrical signal transformed by detector is relatively small, if a higher SNR want to be got, it's necessary to analyze the characteristic of the detector's noise. Considering that follow-up circuit could use the faint reflected laser signal from the target, the pre-amplifier is needed. Therefore, it's important to analyze the noise of pre-amplifier circuit [8].

3.1 Noise characteristics of the photoelectric detector

There are several noises existing in the photoelectric detector [11], but in this detector, there are two kinds of noises: thermal noise and shot noise，which could produce a serious effect on the detector. According to the physical properties of the conductor, the thermodynamic temperature of a conductor above zero has thermal noise. Experimental results show that thermal noise voltage is related to the conductor temperature, the resistance of the conductor and the noise equivalent bandwidth. Thermal noise voltage calculation formula is as follows:

$$U_T^2 = \int_{f_1}^{f_2} 4KTR(f)df \qquad (20)$$

Where K is the Boltzmann Constance, T is the conductor absolute temperature, *R(f)* is the dynamic resistance of the photoelectric detector in the process of laser detection, it changes along with the frequency of the laser.

Since the semiconductor device's working is different from the metal conductor, it has the shot noise. Shot noise current calculation formula is as follows:

$$i_n^2 = 4KTg_0\Delta f - 2qI_S\Delta f \qquad (21)$$

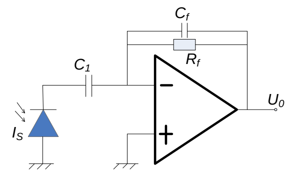
Where g_0 is the low frequency conductivity of the photoelectric detector, I_S is the junction current of the photoelectric detector, q is the electronic charge.

Assuming that the value of *R(f)* is 20 *kΩ*, and detector current is 500 *nA*, for a detector with *10M* bandwidth, when it receives laser signal, thermal noise current is about 2.9 *nA* and shot noise current is about 12.5 *nA*. Therefore, in order to reduce the effect of shot noise effectively, on the case that the bandwidth of the detector meets the requirement for detection, the value of dynamic resistance should be little, and junction current of the detector should be as little as possible. At the same time, bandwidth should be narrowed down as much as possible.

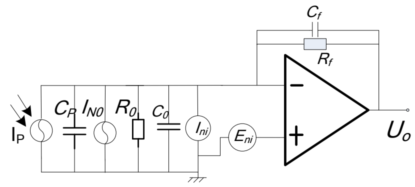
3.2. The research on the noise characteristics of photoelectric detection amplification circuit

In order to amplify the weak signal which is output from detector, the operational amplifier (op-amp) is added. In this case, the SNR of the detection system will be changed. Since the amplifier not only enlarges the weak signal, which is reflected by target, but also the noise is enlarged. At the same time, other noise can be produced by amplifier itself. In order to control the SNR of the detection system, it is necessary to study SNR of the detection system when the operational amplifier is added.

The diagram of the signal amplify circuit for the weak signal is shown in Fig. 3 (a), and the noise model of the photoelectric detection amplification circuit is established, as shown in Fig. 3 (b).



(a)



(b)

Fig. 3. Schematic diagram of the detection amplification circuit and equivalent noise model.

In Fig. 3(b), the I_P is a current caused by laser, including the current caused by laser and the sky background. When the detector receives useless light radiation, the value of the current is zero, vice versa. The C_P is the parasitic capacitance in PIN photoelectric detector; I_{N0} is the total noise current of the photoelectric detector, it involves the thermal noise, shot noise and background noise; R_0 is the output resistance of the detector; C_0 is the output capacitance of the detector; I_{ni} is the input current noise density of op-amp, E_{ni} is the input voltage noise density of op-amp. They are associated with the types of operational amplifier; R_f is the op-amp feedback resistance, as I-V conversion part, the value of impedance is very high, approximately 10^6 Ω; C_f is the compensation capacitance of op-amp, it caused by the op-amp input capacitance of the front-end signal hysteresis characteristics; U_0 is the output voltage of op-amp. The operational amplifier is characterized by a very large open-circuit gain of a million or so. Therefore, the equivalent input impedance of op-amp is as follows:

$$Z = \frac{R}{1+4\pi^2 f^2 C^2 R^2} - j\frac{2\pi f R^2 C}{1+4\pi^2 f^2 C^2 R^2} \qquad (22)$$

In (22), $C = C_0 + C_P + C_f$, $R = (R_0 \times R_f)/(R_0 + R_f)$

According to the theory of conduction electron, the moving electron could suddenly stop in the resistance, so there is thermal noise. However, for the pure reactance, the moving electron can not suddenly stop, so there is no thermal noise. To calculate thermal noise which generated by the equivalent impedance, only resistance thermal noise from the equivalent impedance should be considered. The equivalent noise expression of all the noise in the operational amplifier can be

Eq. (23)

$$\begin{aligned} I_{Ni}{}^2 &= 2qI_S\Delta f + 4KT\Delta f\,\frac{1+4\pi^2 f^2 C^2 R^2}{R} \\ &\quad + I_{ni}{}^2\Delta f + E_{ni}{}^2\left(\frac{1+4\pi^2 f^2 C^2 R^2}{R}\right)^2\Delta f + I_d{}^2 \end{aligned} \qquad (23)$$

Referencing the previous studies on SNR [13], SNR of photoelectric detection circuit of laser detection system can be given by

$$SNR = \frac{I_P}{I_{Ni}} = \frac{I_P}{\sqrt{2qI_S\Delta f + K_1 + I_{ni}{}^2\Delta f + K_2 + I_d{}^2}} \qquad (24)$$

Here,

$$K_1 = 4KT\Delta f\,\frac{1+4\pi^2 f^2 C^2 R^2}{R},$$

$$K_2 = E_{ni}{}^2\left(\frac{1+4\pi^2 f^2 C^2 R^2}{R}\right)^2\Delta f$$

Formula (22), (23) and (24) show that the SNR of detection circuit could be affected by thermal noise, shot noise of detector, op-amp noise, radiation current of background and laser reflected from target. To improve the SNR of the system, the laser illumination L_0 should be strong, the effective reflection area S_0 should be large, and from the point of noise characteristic, the working temperature of detection system should be low, the detector response bandwidth Δf should be narrow, dark current I_D , parasitic capacitance C and output resistance should be small; at the same time, I_{ni} and E_{ni} of the amplifier and feedback resistor should be small. By analyzing those formulas, the influences that various factors on the detection circuit SNR are got. Those studies provide theoretical basis in improving the SNR of the detection system.

The detection performance of the detection system can be estimated from detection distance and SNR. SNR is defined as the ratio of effective current and noise current, effective current which caused by reflected laser radiation. Based on the fact that the nature of detection is that the detection system can detect the minimum reflected laser energy, so it means for a higher SNR, the reflected laser energy can be stronger than noise, and when the reflected laser energy above a certain value, the target can be detected. Otherwise, for a little value of SNR, the value of noise more than the reflected laser, the target can't be detected by the detection system. So a better characteristic on SNR can contribute to the detection on target. More important is that the relation between laser radiation energy and SNR is proportional, which signifies greater laser energy is good for SNR, and also a greater laser means a far detection distance.

4. Simulation and experiment

In this section, to verify and demonstrate effectiveness, correctness of the above theoretical results, the following simulation and experiments are operated.

The operational amplifier - AD826 is selected as the core device, which is used to amplify the weak current signal that caused by laser, and the photoelectric diode - GD3551Y InGaAs PIN is selected as the detector. The detector's operation mode is reverse-biased, when laser detection system works, there will be I_P is 500nA, R_f is *10MΩ* and R_0 is *200KΩ*, for operational amplifier Δf is $2.5MHz$, E_{ni} is $22nV/\sqrt{Hz}$, I_{ni} is $5pA/\sqrt{Hz}$. When the frequency of the laser signal is $10\,KHz$, substitute these parameters into SNR calculation formula (24). By simulating, the relation between the SNR of the photoelectric detection circuit and the feedback resistance R_f is got, as shown in Fig. 4.

The Fig. 4 shows that the influence of feedback resistance on the SNR of photoelectric detection circuit, the SNR of photoelectric detection circuit is inversely related to the resistance. When the value of the feedback resistance is small, the SNR of the detection circuit is high. When the value of the feedback resistance is greater than *1MΩ*, the SNR of the detection circuit is smaller. Moreover, with the increase of the value of the resistance, SNR tends to stable. Therefore, in order to get a higher SNR, the value of the feedback resistance should not be too big, according to Fig. 4, the value of the feedback resistance should be less than *1 MΩ*.

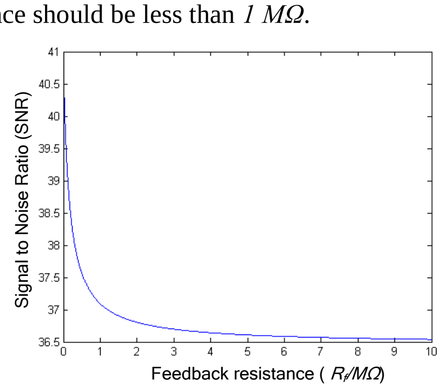


Fig. 4. The relation between SNR and feedback resistance.

To find the way to increase the relative intensity of laser radiation and sky background radiation (P), the simulation about Eq. (17) is done, as shown in Fig. 5, it shows the relation between P, detection distance and target reflection area. By increasing the target reflection area, or diminishing the detection distance, *P* could be improved, the greater the P is, the higher the SNR is. When the distance is constant, with the increase of target reflection area, P is increased linearly, such as AC segment, the segment shows an extremely linear relationship between *P* and target reflection area. When target reflection area is constant, with the increase of the distance, *P* is decreased rapidly, such as the AB curve. Therefore, to increase the value of *P*, it's necessary to enlarge the target reflection area or decrease the detection distance. However, considering that the detection distance is a core parameter for detection system, it is good for P at a proper value which is not higher; otherwise, the detection performance will be diminished.

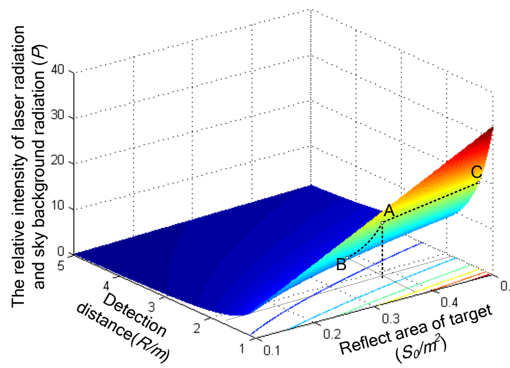


Fig. 5. The value of the relative intensity of laser radiation to sky background radiation (P), with the changing of detection distance and target reflection area.

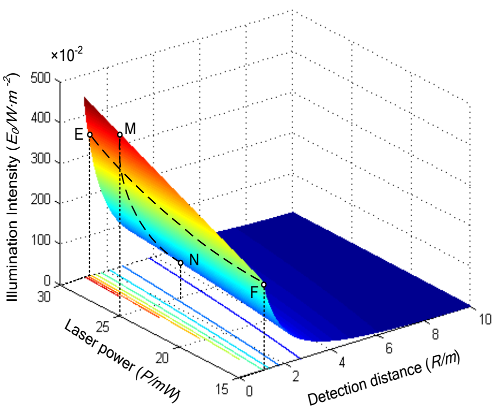


Fig. 6. The changing between illumination intensity, laser power and detection distance.

Fig. 6 shows the relationship between the illumination intensity, laser power and the detection distance. The figure demonstrates that when the laser power is stronger and the detection distance is shorter, and then the illumination intensity will be higher. When the laser power is constant, with the increase of distance, the attenuation of the illumination intensity by exponential law, this phenomenon is consistent with experiments. At the same time, it shows that when the laser power is smaller, the illumination intensity is smaller, as well. It's consistent with experiment that the luminous power is smaller, and the change of the SNR is slower. When the distance is constant, the relationship between the illumination intensity and laser power is EF curve, and this relation is consistent with the experimental data in Table 2, from which we could easily get the relation between the illumination intensity and laser power.

In reality, the reflection characteristic is a directional reflection, which is between plane reflection and diffuse reflection. Therefore, it's necessary to analyze the reflection efficiency that target to laser, in laser detection system. By using the Bidirectional Reflectance Distribution Function to study the target reflection characteristic, the relation between target reflection efficiency, incident angle and specula index is got, as is shown in Fig. 7, it shows that the incident angle α of laser in target has a great influence on reflection efficiency. When incident angle α is greater than *1 rad* or less than *-1 rad*, target reflection efficiency begins to weak, and this means that the detector will not receive any photons with an incident angle α greater than *1 rad* or less than *-1 rad*. Therefore, in order to get a higher SNR, the incident angle α should be limited *-1 rad* to*1 rad*, otherwise, the target can't reflect laser to the detector, and then the SNR of the system will be reduced.

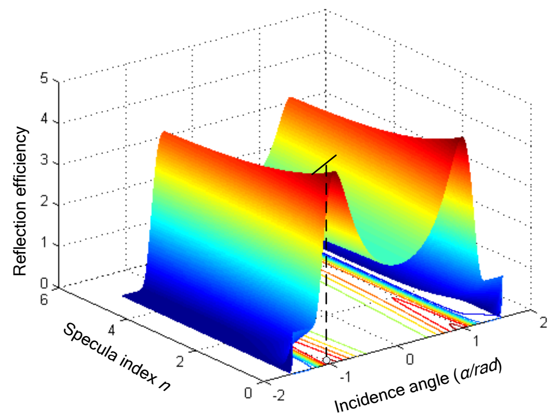


Fig. 7. The changing between reflection efficiency, specula index and incidence angle.

In order to explore the influence that the feedback resistance of the photoelectric detector amplifying circuit on the SNR, the experiment measures the data of feedback resistance, the voltage peak of reflection echo signal and noise. According to the mathematical expression of SNR, SNR could be calculated. Making simulation for the data in Table 1, the curve is got in Fig. 8, the curve fitting is acquired through 3 times fitting for the data. The analysis is done through MATLAB modeling which based on experimental data obtained from the pre-detection circuit. Comparing Fig. 4 with Fig. 8, it suggests when feedback resistance is less, the SNR is higher, with the increase of the feedback resistance, and the SNR of the system will be reduced. In the experiment, when the value of feedback resistance increases to 3MΩ, SNR tends to stable. This is account for with increasing of the resistance, resistance plays a dominant role than other factors on SNR, and the changes in resistance and SNR is inverse proportional relationship, which meaning with increasing of the resistance, the change in SNR is little. At the same time, the data show that the value of SNR is little than theoretical value, the reason for this is that the theoretical analysis ignores the influence of other factors on SNR, such as $\frac{1}{f}$ noise, or some of the laser signal is mistaken for noise when analyze the noise from experiment condition.

Table 1. The voltage peak of reflection echo signal and noise with the change of feedback resistance.

Num	Feedback resistance ($M\Omega$)	Signal voltage peak （mV）	Noise voltage peak (mV)	SNR
1	0.2	220	9	24.4
2	0.5	352	14	25.1
3	0.8	630	28	22.0
4	1	781	44	20.2
5	1.5	1065	57	18.7
6	2	1349	82	16.5
7	2.5	1846	124	14.9
8	3	2200	147	15.0
9	4	2690	172	15.6
10	5	3720	250	14.9

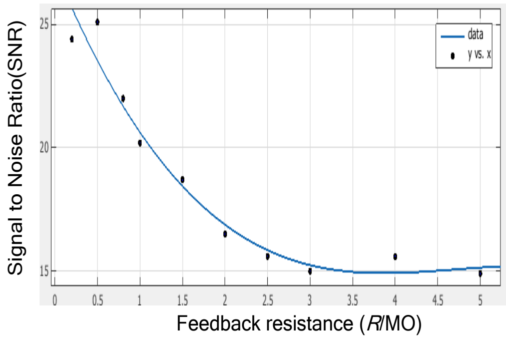


Fig. 8. The relation between SNR and feedback resistance in experiment.

Changing the laser power, the voltage peak of reflection echo signal and noise could be got, as shown in table 2. By simulating the data in table 2, the curve shown in Fig. 9 is got, the curve fitting gets from fitting the data in table 2. The analysis shows that when laser power is less, the SNR of the system couldn't be improved prominently; it is the result of laser power is shortage and the laser is decayed in propagation, thus the photons number will be reduced when it arrives at receiving lens. When the laser power is less, the change rate of the amount of the photons is greater, and then the value of η will be decreased, as a result, the capability of photons to current transition will be weaken. With the increasing of laser power, when it comes to $26mW$, the SNR of the system will be reduced, it's the result of the distance that laser device to detector is short. When the laser works, it generates a great electromagnetic interference (EMI) which makes laser detection system develop a strong interference between laser and photoelectric detector, since EMI could increase the noise current, and then the SNR of the detection system will be reduced. To get a higher SNR, this effect should be avoided.

Table 2. The voltage peak of reflection echo signal and noise with the change of laser power.

Num	Laser power （mW）	Noise voltage peak (mV)	Signal voltage peak （mV）	SNR
1	15	24	367	15.3
2	16	28	422	15.1
3	17	28	467	16.7
4	18	31	527	17.0
5	20	41	737	18.0
6	22	57	1065	18.7
7	24	75	1487	19.7
8	26	96	1980	20.6
9	28	120	2337	19.5
10	30	151	2720	18.0

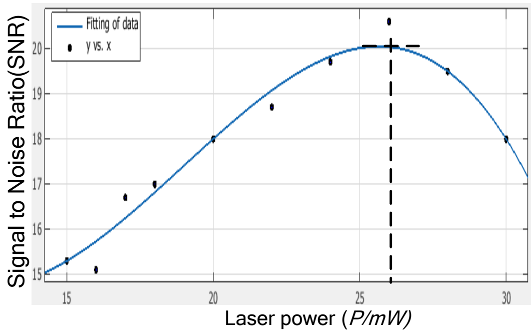


Fig. 9. The relationship between SNR and laser power.

To make a comprehensive analysis on Fig. 6 and Fig. 9, the relation between the laser power, detection distance and SNR could be got further. Considering that detection distance and the pupil illumination is a proportional relationship, assuming the minimum level that the system can detect the target for pupil illumination is above $100\times10^{-2}(W/m^2)$, and then with increasing of laser power, SNR is improved gradually, the pupil illumination is enhanced, as well. At this time, the distance could be increased to l^*, until the illumination value satisfy the minimum illumination value of $100\times10^{-2}(W/m^2)$, as Fig. 6 curve MN shown, and then the maximum distance detection is l^*. However, with the laser power increase to 26mW, the value of SNR began to decrease, it means that the noise received by detector bigger than the minimum useful laser signal which is used to detect the target. It signifies the detection system disabled to detect the target at minimum illumination value of $100\times10^{-2}(W/m^2)$. Therefore, in order to get the maximum detection distance, the most value of laser power is 26mW.

5. Conclusions

The factors, which influence the detection performance of laser photoelectricity detection system, caused by the sky background illumination, laser radiation and detection circuit noise are analyzed. And Bidirectional Reflectance Distribution Function and finite element analysis method are applied into the analysis of target reflection characteristics, and then the mathematical expression about the laser reflected from target is derived, thereby, the mathematical function about detection distance and laser illumination is got. By establishing the detection circuit equivalent noise model, the formula about the SNR of the detection system is achieved. The simulating and experimental results show that SNR is affected by the feedback resistance and the laser power. The target reflection characteristic is affected by the incident angle of the laser in target, and most important is that the relation between detection distance, laser power and SNR is derived. These studies provide experimental demonstration for improving the detection performance of the detection system. Compared with the previous research on detection performance of detection system, the results of these studies have more advantages, laying a solid foundation for detection performance analysis of the detection system as well as providing practical guidance for practice.

References

[1] Hanshan Li, Zhiyong Lei, IEEE sensors journal, **13**(5), 1959 (2013).
[2] Wenyu Fu, Journal of photoelectric technology, 24 (2003).
[3] Hanshan Li, Junchai Gao, Zemin Wang, Optik, **125**(3), 1325 (2014).
[4] Guang Chen, Xin Wang, Siqiang Fan, He Tang, Lin Lin, Albert Wang, Tsinghua Science & Technology, **15**(3), 259 (2010).
[5] Chunyong Wang, Jin Wei, Journal of Beijing institute of technology, **23**(5), 617 (2003).
[6] Hanshan Li, Zhiyong Lei, Sensor review, **33**(4), 315 (2013).
[7] S. K. Nayar, K. Ikeuchi, T. Kanade, Analysis and Machine Intelligence, **13**(7), 611 (1991).
[8] Franck Pastor, Etienne Loute, Journal of Computational and Applied Mathematics, **234**(7), 2213 (2010).
[9] Cai Lei, Shijiang Zhang, Xiaowei Guan, Laser and particle beam., **25**(7), 1671 (2013).
[10] Baishun Zhang, Wenying Liu, Qingnong Wei, Optical technique, **32**(2), 180 (2006).
[11] Hanshan Li, Zhiyong Lei, Zemin Wang, Junchai Gao, Journal of Nanoelectronics and Optoelectronics, **7**(2), 199 (2012).
[12] Zhengqi Liu, Fuwen Yu, Journal of yanan university, **22**(4), 41 (2003).
[13] Guo Wei, Jian Zhou, Xingwu Long, Optics & Laser Technology, **44**(1), 108 (2012).
[14] Jiangtao Song, Xiangheng Shen, Optics and Precision Engineering, **18**(5), 1036 (2010).

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