On echo signal of complex cloud background based on narrow pulse laser detector

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Abstract

In consideration of the poor ability of anti-interference to cloud of the present laser detector, the characteristics of laser back scattering is studied according to the extinction coefficient of cloud, so as to build a signal-to-noise ratio model under the backgrounds of uniform and non-uniform cloud. In addition, under the condition of certain laser energy, the simulation and experimental analysis on the echo signal of laser detection with different pulse width of 100 ns, 10 ns and 1 ns are conducted. The analysis shows that the result of the experiment and calculation are perfectly in accordance with each other, and the narrower the pulse width of lasing is, the higher the signal-to-noise ratio of the system is, that is, the higher the ability of anti-interference to cloud of the laser detection system is. Undoubtedly, this is of great significance in the improvement on the ability of anti-interference to cloud, the enlargement of the distance and the enhancement of the accuracy of the laser detector.

Keywords: Narrow Pulse Laser; Cloud Background; Characteristics of Back Scattering; Signal-to-noise Ratio

1 Introduction

Cloud is of great influence on the decay of electric wave and scattering noise, especially on the coverage, detection rate, false alarm rate, detection threshold and sensitivity of the micro wave, millimeter wave and laser[1-3]. Without the decay and scattering in the transmission of laser, the coverage and detection threshold of the laser detection system cannot be determined. Moreover, without the background noise and transmission data of the target, the acquisition, detection and process of the information of the target cannot be realized. Furthermore, without a comprehensive consideration on the different characteristics of transmission and noise, the optimum parameters of the system cannot be appropriately determined. Therefore, the study on the characteristics of the cloud in the scattering and radiation of laser pulse is of great practical value.

Compared with traditional laser detector, the narrow pulse laser detector is greatly improved in the ability of anti-interference to cloud, the distance and accuracy of detection[4-5]. In the laser detection system, before irradiating on the target, when the laser passes through the complex atmosphere (mainly with a consideration on the different cloud barriers), the field intensity and phase of the laser are all changed. Moreover, after being scattered by the target, when the laser passes through the atmosphere again and gets to the laser detector, the laser is influenced again by the cloud. Therefore, the study on the characteristics of back scattering of cloud background is of great significance in the improvement on the accuracy of the laser detector.

2 Characteristics of laser back scattering of cloud

When the light impulse emitted by the laser detector is influenced by the different suspended particles, such as, the cloud and raindrops in the spatial path, some signals of the light impulse will be back scattered[6-9]. Therefore, in this paper, the Mie scattering theory is used to calculate the decay of the light pulse with a width of 1.06 μm, which is approximate to the ionic radius of the cloud and raindrops. Here, the decay of cloud can be calculated by the equation (1):

$$A = 4.343 \cdot 10^3 \int_0^\infty Q_e(r) n(r) dr . \tag{1}$$

Hereinto, the extinction cross section of cloud droplet is $Q_e(r)$, the model for the distribution of particle is $n(r)$, and the semi-diameter of cloud droplet is r. In addition, in this formula, the size of the distribution of the cloud droplet should be considered.

In the theory of Mie, essentially, the calculation on the particle scattering intensity can be regarded as the calculation on the scattering cross section $Q_s(r)$ and the

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extinction cross section $Q_e(r)$. When the scattering cross section is much greater than the absorption cross section, the extinction coefficient $\sigma(\lambda)$ is approximately equal to the scattering coefficient σ_{sc}. As for the gasoloid, if its model for the particle distribution is $n(r)$,r is $\lambda\alpha/2\pi$, according to the particle size distribution, the extinction coefficient of the particles can be calculated as follows:

$$\sigma(\lambda) = \int_{x_1}^{x_2} Q_e(r)\pi(\lambda\alpha/2\pi)^2 n(\lambda\alpha/2\pi)d\lambda\alpha/2\pi \qquad (2)$$

According to the equation 2, the extinction coefficients under different clouds can be worked out, as shown in the Table 1.

TABLE 1 Calculation Values of Extinction Coefficient under the Wave Length of 1.06μm

Cloud type	Water content W(g/m2)	Particle radius($r/\mu m$)	Extinction Coefficient (m-1)
Altostratus	0.10	40.00	**1.52*10-1**
Stratocumulus	0.25	10.00	**4.93*10-2**
Stratus	0.15	20.00	**7.01*10-2**
Nimbostratus	0.01	0.05	**1.68*10-1**
Fair Wx cumulus	0.50	10.00	**2.34*10-2**
Cumulus Congestus	**0.80**	**0.50**	7.65*10-2

From Table 1,it can be concluded that the extinction coefficients can be used to build a simulation model. In another word,by adopting the iterative algorithm, the extinction coefficients can be worked out under different cloud models, which will provide a more reliable theoretical model for the build of data base of extinction coefficient under different clouds.

3 Build of the simulation model for the signal-to-noise ratio in laser detection system

Compared with coherent detection sharing the characteristics of higher sensitivity but difficult to be realized, direct detection is easier to be realized in the ultra-short pulse laser detection system. Here, an avalanche photo diode (APD) with the internal gain M and a head amplifier composed by the FET output and broadband operational amplifier are adopted in the laser detector[10].

Currently, the noise in the ultra-short pulse laser detection system[11-14] can be divided into two kinds, one is the background noise, mainly based on the above analysis of the noise interference of the cloud background, that is, uniform and non-uniform cloud, the other is the noise interference in the head amplifier and the main amplifier.

In the convenience of engineering calculation, on the assumption that the current of the head amplifier is i_{preamp}, and the equivalent bandwidth of noise is BW, the noise current of the main amplifier can be worked out as follows:

$$i_{amp}{}^2 = i_{preamp}{}^2 BW \qquad (3)$$

$$i_{bg} = \sqrt{2qi_d BW} \qquad (4)$$

In the equations, i_{bg} is the current of background, the electron charge q is 1.6×10-19C, and i_d is the positive junction current, which can be worked out through the following equation:

$$i_d = L_{cloud} A_{lens} \theta_{Rx}^2 T_{Rx} \Delta\lambda_{Rx} \qquad (5)$$

In this equation, the spectral radiance is $L_{cloud}[W/m^2 sr\mu m]$, the area of lens A_{lens} is $\pi(\frac{d_{lens}}{2})^2$, the angle of θ_{Rx} is the field of view, and T_{Rx} is the efficiency of the receiver optical system.

Due to the fact that the thermal noise current and the noise current of the dark current of photosensitive tube can be approximately regarded as the noise current of the main amplifier, the signal-to-noise ratio of the receiver can be expressed as:

$$SNR = \sqrt{i_{sig}^2 / (i_{amp}^2 + i_{bg}^2)} \qquad (6)$$

However, because the each part in the detection system is needed to be analyzed to build the model for the signal-to-noise ratio, without a consideration on the signals scattered back by the cloud, only the decay of the target signal in the cloud is considered, then, the noise current of the background and system can be worked out.

As the noise current of the main amplifier and background radiation have been given in the above description, the following is mainly about the acquisition of the current of the target echo signal.

On the assumption that the detector power reflected back from the target is:

$$P_{det} = I_{tar} T_{atmos} \tau_{lens} \frac{A_{lens}}{R^2} = \rho_{tar} \frac{Q_{laser}}{t_{TX}} \cdot T_{Tx} \cdot T_{Rx} \exp[-2\sigma(\lambda) \bullet R] \frac{d_{lens}{}^2}{4R^2} \qquad (7)$$

The corresponding current of the signal is:

$$i_{sig} = P_{det} M \Re \qquad (8)$$

Hereinto, ρ_{tar} is the general reflection index of the target, Q_{laser} is the output energy of the laser, t_{TX} is the impulse width of the laser, T_{TX} is the efficiency of the optical part of the laser emitter and scanner, T_{Rx} is the efficiency of the receiver optical system, $\sigma(\lambda)$ is the cloud extinction coefficient, R is the distance from the laser to target or the distance of the laser-beam penetrating through the cloud, d_{lens} is diameter of the receiver optical device (input port), M is the internal gain of the assumptive avalanche detector, and $\Re$ is the responsivity of the detector.

Through the substitution of the equations (3), (4), (5), (7)and (8) into the equation (6), after calculation, the simulation model for the signal-to-noise ratio of the system can be built as follows:

$$\frac{S}{N}=\rho_{tar}\frac{Q_{laser}}{t_{TX}}\cdot T_{Tx}\cdot T_{Rx}\cdot\exp[-2\sigma(\lambda)\bullet R]\cdot\frac{d_{lens}^{\ 2}}{4R^2}\cdot M\Re/\sqrt{(\frac{1}{2}qL_{cloud}\pi d_{lens}^{\ 2}\theta_{Rx}^2T_{Rx}\Delta\lambda_{Rx}+i_{preamp}^2)BW} \tag{9}$$

4 Analysis on the result of simulation

4.1 SIMULATION ON THE SIGNAL-TO-NOISE RATIO OF THE DETECTION SYSTEM IN THE UNIFORM CLOUD BACKGROUND

Under the condition that Q_{laser} is 6 μJ , A_{lens} is 0.031mm^2,T_{Tx} is 0.7,T_{Rx} is 0.5, ρ_{tar} is 0.3, $\sigma(\lambda)$ is 0,when the impulse width of the laser emitter t_{TX} is 1ns, 10ns and 100ns respectively, the simulation curve for the signal-to-noise ratio of the detection system can be got, as shown in the Figure 1.

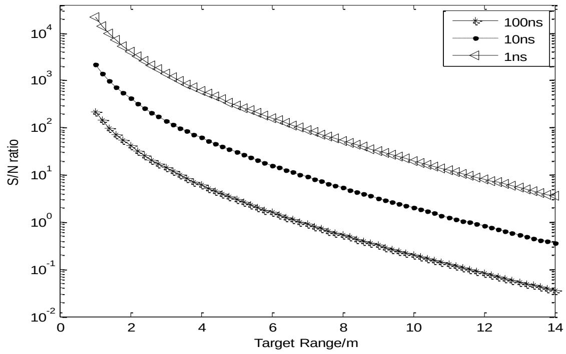

FIGURE 1 SNR Curve with Different Pulse Widths When the Extinction Coefficient of the Cloud and Mist Is 0.132

In the Figure 1, it can be seen from the three curves, under the same condition, the narrower the impulse width of the laser detector is, the higher the signal-to-noise ratio is.

4.2 SIMULATION ON THE SIGNAL-TO-NOISE RATIO OF THE DETECTION SYSTEM IN THE NON-UNIFORM CLOUD BACKGROUND

In this paper, the equations of the laser emitter and receiver of the simulation model for the signal-to-noise ratio in the non-uniform cloud background are the same with that of the uniform cloud background.

Although the cloud is non-uniform, in the process of building the model, the cloud can be divided into a plurality of sections, and the each cloud section is uniform. Therefore, through a superimposition on the extinction coefficient and the coefficient of scattering of the each cloud section, the back scattering intensity of the echo wave from the target after the laser penetrating through the cloud can be worked out, then, the model for the echo wave of the back scattering after the laser penetrating through the non-uniform cloud can be built, as shown in the Figure 2.

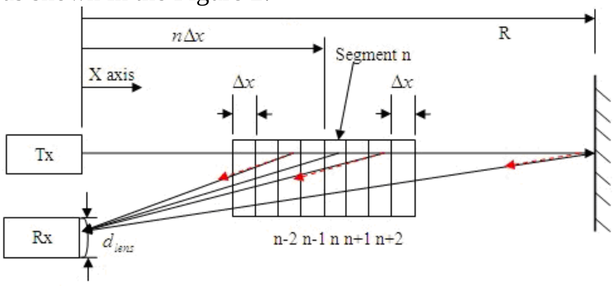

FIGURE 2 Model for the Echo Wave of the Back Scattering after the Laser Penetrating through the Non-Uniform Cloud

Within the detection range from 0 to 15 meters, taking 0.06m as the step length, different models for the atmosphere can be built by a combination on the different clouds in the Table 1 with the method of random sampling. The parameters of the model A are shown in the Table 2.

TABLE 2 .Parameters of the Model A

Atmospheric Path Type			**Atmos Four**		
Cloud data			**Cloud and target**		
n	Range	Type A	Extinction coeff	Backscatter coeff	**Transmission**
0	-0.3	11	5.00E-04	1.00E-07	**1.00**
1	-0.24	11	5.00E-04	1.00E-07	**1.00**
2	-0.18	11	5.00E-04	1.00E-07	**1.00**
3	-0.12	11	5.00E-04	1.00E-07	**1.00**
4	-0.06	11	5.00E-04	1.00E-07	**1.00**
5	0	11	5.00E-04	1.00E-07	**1.00**
6	0.06	10	1.70E-03	2.00E-06	**1.00**
7	0.12	10	1.70E-03	2.00E-06	**1.00**
8	0.18	10	1.70E-03	2.00E-06	**1.00**
9	0.24	10	1.70E-03	2.00E-06	**1.00**
10	0.3	10	1.70E-03	2.00E-06	**1.00**
11	**0.36**	**10**	**1.70E-03**	**2.00E-06**	**1.00**

Figure 3 indicates the echo signal of the target detected by the laser detector in the model A, when the energy of the laser is $1\times10^{-5}J$, and the impulse width is $1ns$. It can be seen from Figure 3, when the impulse width of the pulsed laser emitted by the laser detector is 1ns, under the condition of complex cloud, the waveform of the echo wave resulted from the cloud and the waveform resulted from the target detected by the laser detector are difficult to be distinguished in amplitude. However, after being enlarged by the amplifier of the distant gain, as shown in the Figure 4, the echo wave amplitude resulted from the target is obviously higher than that of the noise resulted from the cloud barriers, and the impulse width of the echo wave resulted from the target is fairly narrow, thus, the target and the cloud barriers are well distinguished out.

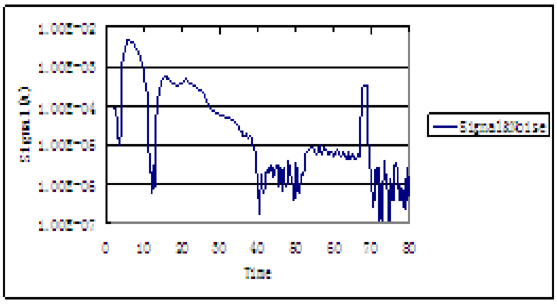

FIGURE 3 Echo Signal in Laser Detection System

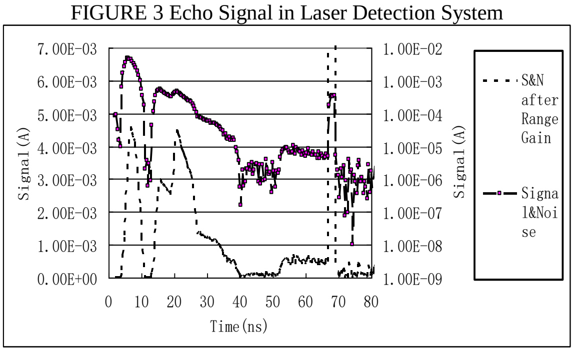

FIGURE 4 Graphic after the Process of Signal Received by the Detector at the Position Of Distant Gain

According to the same method, when the impulse width of the laser detector is 10ns, as shown in the Figure 5, the echo signals of the system are. It can be easily concluded from the Figure 4 and 5, under the condition of certain energy of laser detector, the wider the impulse width is, and the lower the signal-to-noise ratio in the system is. Therefore, it is of great importance for the adoption of laser detector with narrow impulse width in the improvement of the signal-to-noise ratio in the system.

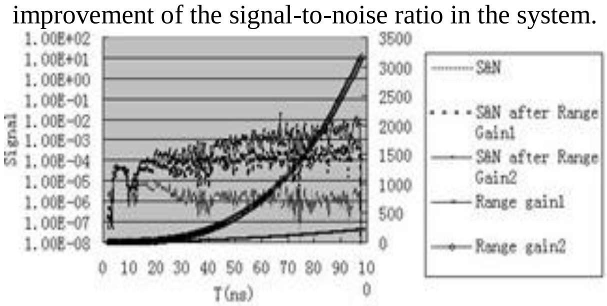

FIGURE 5 Echo Signal of Laser Detection System with Q_laser is 1*10-5*J* and t_tx is 10ns

5 Analysis on the Result of Experiment

In this paper, some coherent experiments are made on the signal-to-noise ratio under the conditions of uniform and non-uniform cloud background with the experimental equipments, such as, a YHJ102 laser with the wave length of 1.06 μ m and the impulse width of 1ns, a laser with the wave length of 1.06 μ m and the impulse width of 3ns, a YHTC-IRM01 laser, a MS06104A, a regulated power supply, six ultrasonic transducers and a cylinder cloud entryway made by aluminum. When the experiment is conducted in the indoor with the temperature is 15^0C, the humidity is greater than 60% and the local atmospheric pressure is 980.4hPa, the result of the experiment can fell into three types, that is, when the impulse width is lns (under the condition of thin cloud),the graphic for the echo wave is shown in the Figure 6,when the impulse width is lns (under the condition of thick cloud), the graphic for the echo wave is shown in the Figure 7, and when the impulse width is 3ns (under the condition of cloud and target), the graphic for the echo wave is shown in the Figure 8.

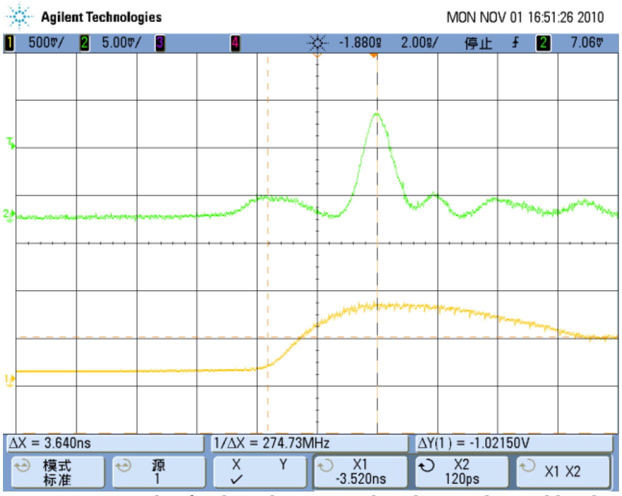

FIGURE 6. Graphic for the Echo Wave When the Impulse Width is lns (under the Condition of Thin Cloud)

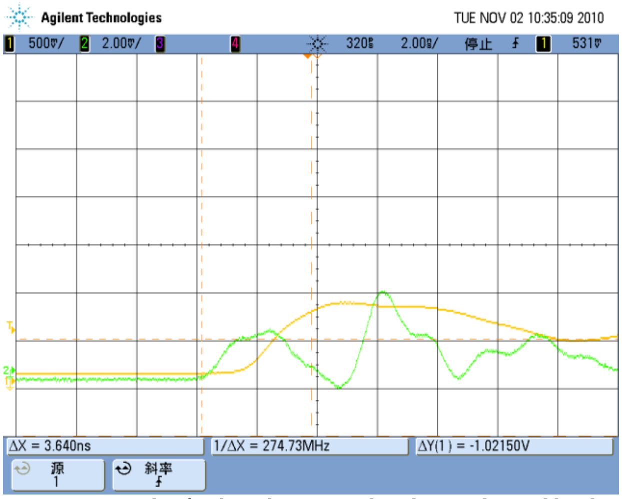

FIGURE 7 Graphic for the Echo Wave When the Impulse Width is lns (under the Condition of Thick Cloud)

From the analysis on the above graphics, when the laser detector with the impulse width of 1ns, is adopted as the emitter of the detection system, compared with the laser detector with the impulse width of 3ns, the ability of anti-interference to the cloud is greatly improved.

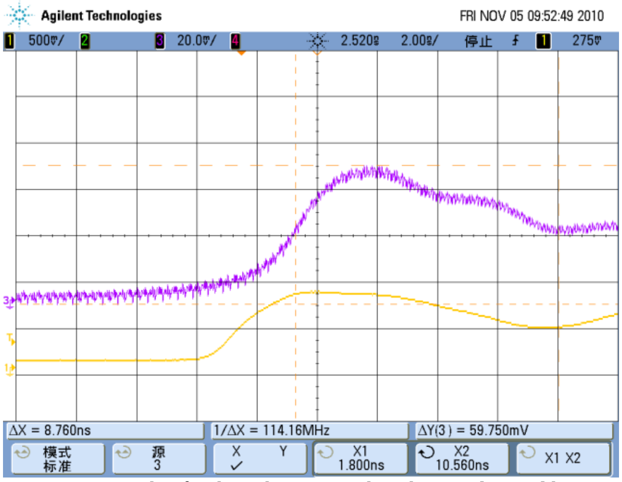

FIGURE 8 Graphic for the Echo Wave When the Impulse Width is 3ns

6 Conclusion

Through the analysis on the model for the echo signal of complex cloud background based on narrow pulse laser detector, it can be concluded that the laser detector with the narrow impulse can greatly improve the ability of anti-interference to the cloud of laser detector, and the target and the cloud barriers can be well distinguished out.

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