

Study on the transmission properties in the rain of 532nm laser

ZhiJing Wang, Ning Shan & Hao Wang

School of CAPF Engineering University, Xi'an 710086, China

Keywords: rainfall, laser attenuation, Mie scattering

Abstract. The laser beam will be severely attenuated in the rain to transmit unable to complete the scheduled tasks arriving at the role of target. On the attenuation characteristics of laser in the rain in the infrared wave band has conducted in depth study, but in the visible range it is lack of study. In this paper, I will study the attenuation model of 532nm laser in the rain, and get result through theoretical analysis and numerical simulation: In the same rainfall rate of 532nm laser attenuation effect in the light will be more obvious than in heavy rain, while in the same weather, the more heavy of rainfall the more deficit of laser attenuation. The result shows that the number of raindrops in light rain is are more than that in the heavy rain, and laser multiple scattering effect will be more significant.

Introduction

Laser has a good coherence, high brightness and concentrated energy [1], receiving widespread and increasingly great attention from scientists, especially in the military and medical field. Currently, laser applications in the military are mainly reflected by laser cause of blindness, laser guidance and laser communication. However, laser would suffer different degrees of attenuation in different environments, thus resulting in a failure of completing tasks. Under the near-Earth atmospheric conditions, transmissions of laser are mainly affected by rain, fog, haze and absorption and scattering of aerosol particles in the air, which causes a system performance degradation. Numerous studies have been made on transmission characteristics of infrared laser. However, few studies have been made on transmission characteristics of laser within the visible light band. 532-nm green laser is usually taken as an excitation source of causing non-lethal laser blindness, so the attenuation characteristics of the 532-nm green laser can provide a theoretical basis for improving the non-lethal laser blinding weapons. Rainfall is a common natural phenomenon. Transmissions of laser beams are extremely complex, including raindrops' absorption, scattering and refraction of laser beams. However, for 532-nm laser beams, the main influence of raindrops on laser transmissions is reflected by raindrops' scattering of laser which is determined by the raindrop size distribution. Therefore, in this paper, the Weibull distribution is taken as the raindrop size distribution to analyze attenuation of 532-nm laser in the rain.

Laser In-rain Attenuation Model

From the literature [2], the scattering light intensity of laser whose incident light intensity I_0 is 0.05W and wavelength is 532nm is shown in Fig 1.

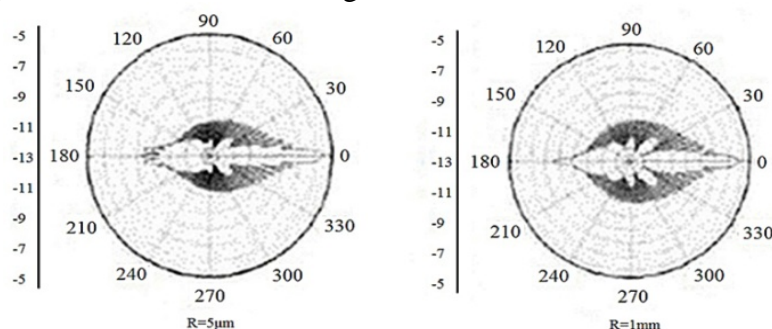


Fig 1 Logarithmic light intensity of laser when the incident wavelength λ is 532nm

Raindrops' scattering of laser can be divided into forward scattering, backward scattering and lateral scattering, according to different scattering angles. the 532-nm laser mainly experiences forward and backward scattering. For laser of the same wavelength, the greater the radius of raindrop particles is, the smaller the lateral scattering light intensity of laser would be. The concentration ratio of forward and backward scattering of raindrops with particle radius of 1mm is greater than that with particle radius of 5μm.

The raindrop shape is an important factor in research on the laser transmission in the rain. According to the literature [3], common approximation models of raindrop shapes mainly include the PP model, BC model and the approximate ellipsoid model and so on. In order to simplify calculations in this research, the PP model is used. With the PP model, laser scattering of raindrops can be explained based on the Mie Scattering Theory [4]. The expression for the attenuation factor Q_e , the scattering efficiency factor Q_s and absorption efficiency factor Q_R is:

$$Q_e = \frac{2}{\chi^2} \sum_{n=1}^{\infty} (2n+1) \text{Re}(a_n + b_n) \quad (1)$$

$$Q_s = \frac{2}{\chi^2} \sum_{n=1}^{\infty} (2n+1) (|a_n|^2 + |b_n|^2) \quad (2)$$

$$Q_R = Q_e - Q_s \quad (3)$$

Where, χ is the particle size parameter $\chi = 2\pi R/\lambda$; λ is the incident wavelength; R is the particle radius; a_n and b_n are Mie coefficients.

$$a_n = \frac{\varphi_n(\chi)\varphi'_n(m\chi) - m\varphi'_n(\chi)\varphi_n(m\chi)}{\xi_n(\chi)\varphi'_n(m\chi) - m\xi'_n(\chi)\varphi_n(m\chi)} \quad (4)$$

$$b_n = \frac{m\varphi_n(\chi)\varphi'_n(m\chi) - \varphi'_n(\chi)\varphi_n(m\chi)}{m\xi_n(\chi)\varphi'_n(m\chi) - \xi'_n(\chi)\varphi_n(m\chi)} \quad (5)$$

In this formula:

$$\varphi_n(x) = \sqrt{\frac{x\pi}{2}} J_{n+1/2}(x) \quad (6)$$

$$\xi_n(x) = \sqrt{\frac{x\pi}{2}} H^2_{n+1/2}(x) \quad (7)$$

In the above formula, $J_{n+1/2}(x)$ 、 $H^2_{n+1/2}(x)$ are respectively the Bessel function and Hankel function while m is the compound refractive index of particles. The attenuation coefficient is:

$$\alpha = 4.343 * 10^3 * \frac{\pi}{4} \int_{D_{\min}}^{D_{\max}} Q_e D^2 N(D) dD \quad (8)$$

Where, $N(D)$ is the raindrop size distribution function; D is the diameter of raindrops; D_{\max} and D_{\min} are respectively the maximum diameter and the minimum diameter of the raindrops.

Raindrop size distribution function

The raindrop size distribution function is an important parameter in research on attenuation characteristics of laser in the rain. The raindrop size distribution, also known as rain droplet size spectrum, refers to the distribution of raindrops with different diameters ranging from D to $D + \Delta d$ per unit volume, that is, the distribution of raindrop sizes per unit volume. At present, frequently-used distributions include the Laws-Parsons distribution, the Marshall-Palmer distribution, Gamma distribution and Weibull distribution. In this paper, the Weibull distribution is used for analyses.

M-P distribution (negative exponential distribution) is a widely-used raindrop size distribution model. It was presented by Marshall and Palmer based on data obtained by measurement and data of Laws-Parsons distribution. Its expression is:

$$N(D) = N_0 \exp(-4.1H^{-0.21}D) \quad (9)$$

Where, N_0 is the spectral parameter; N_0 is 8000 ($m^{-3}mm^{-1}$); H is the rainfall intensity (mm/h); D is the diameter of raindrops.

With scholars made more in-depth studies on the raindrop size distribution, they found that N_0 was also affected by the rainfall intensity. In order to get a more accurate raindrop size distribution model, in 1984, the Gamma distribution model was built by Ulbrich and other scholars to gain better results. The Gamma distribution was developed by introducing a shape factor μ into the MP distribution.

$$N(D) = N_0 D^\mu \exp(-\Lambda D) \quad (10)$$

Compared to the Marshall-Palmer distribution and Gamma distribution, it would be more simple and convenient to use the Weibull [6] presented by Sekine and Lind in 1982 to make calculations in research. The Weibull distribution is widely applied to raindrop size distribution models in places all over the world. Its expression is:

$$N(D) = N_0 \frac{\eta}{\sigma} \left(\frac{D}{\sigma} \right)^{\eta-1} \exp \left[- \left(\frac{D}{\sigma} \right)^\eta \right] \quad (11)$$

Where, N_0 is $1000m^{-3}$; η is $0.95H^{0.14}$; σ is $0.26H^{0.42}$; H is the rainfall intensity; the unit is mm/h .

Matlab simulation can be made to figure out the raindrop size distribution in the case of different rainfall rates, as shown in Fig 2.

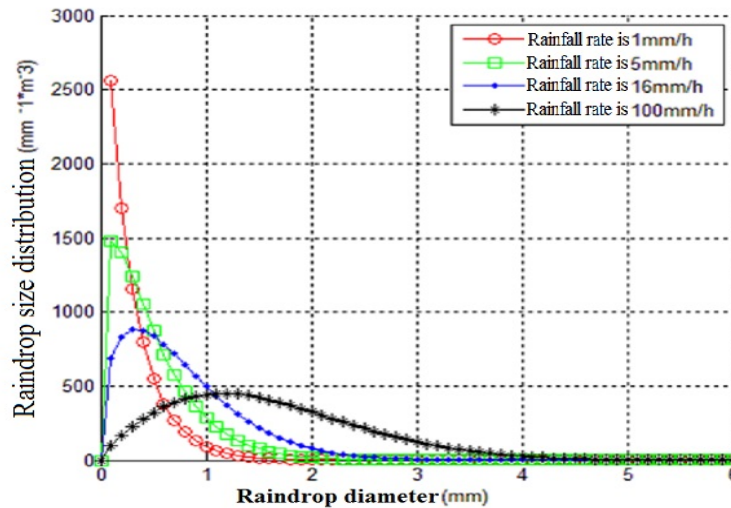


Fig 2 Raindrop size distribution in the case of different rainfall rates

As can be seen from Fig 2, along with an increase in raindrop diameters, the distribution of the number of raindrops with different sizes in the case of different rainfall intensities is shown. It can be seen that the overall trend is to increase and then gradually decrease. In the rain, the number of small raindrops is always greater than that of large raindrops. In general, diameters of most raindrops are around 0.5 mm. Moreover, the numbers of raindrops are basically the same in the case of different rainfall intensities and the raindrop sizes range between 1mm and 6mm. The higher the rainfall intensity is, the greater the number of large raindrops would be and the more equal the distribution of the number of raindrops with different sizes would be.

Attenuation numerical simulation of 532-nm green laser in rain

The complex refractive index of 532-nm laser when it is transmitted in the rain is $m = 1.332 - 1.96 \times 10^{-9}i$, Its extinction efficiency factor Q_e , the scattering efficiency factor Q_s and the absorption efficiency factor Q_R are series of n terms. So as to avoid the complexity of the calculation work, n is usually taken on as 800, to figure out relationships between the extinction efficiency factor Q_e , the scattering efficiency factor Q_s and the absorption efficiency factor Q_R . Computer simulation is made to get the relational Fig of the extinction efficiency factor Q_e , the scattering efficiency factor Q_s and the absorption efficiency factor Q_R , as shown in Fig 4.

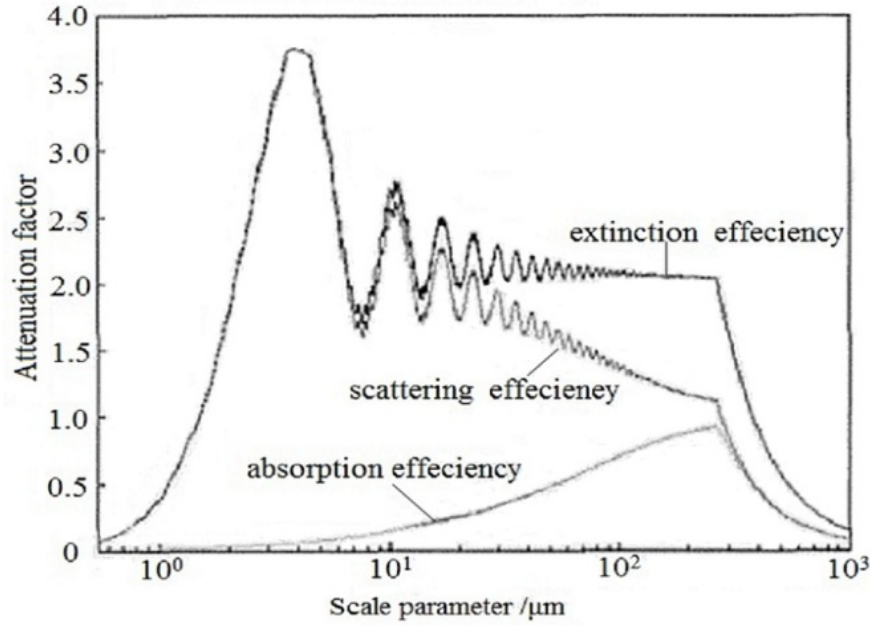


Fig 3 Relational Fig of attenuation factors and scale parameters

According to the Fig 3, it can be seen that the relational Fig is composed of a series of oscillation curves. The attenuation factors change constantly centered by 2, which is in line with the result that the attenuation factor is calculated as 2 according to the Van de Hulst approximation formula [8]. In this way, the value of the attenuation factor calculated based on the Van de Hulst approximation formula to further simplify the formula calculating the attenuation factor α :

$$\alpha = 4.343 * 10^3 * \frac{\pi}{2} \int_{D_{min}}^{D_{max}} D^2 N(D) dD \quad (12)$$

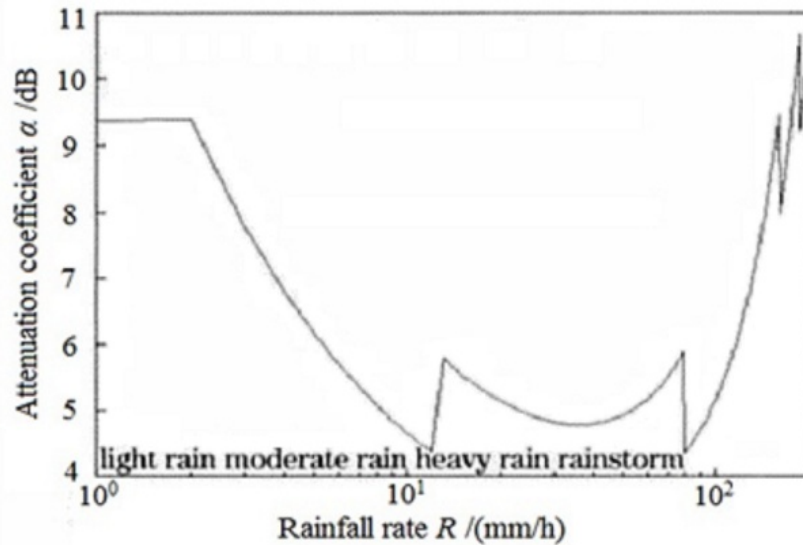


Fig 4 Relational Fig of attenuation coefficient and rainfall rate

From Fig 4, it can be clearly seen that the laser attenuation in light rain is significantly greater than in moderate and heavy rain, because the number of raindrops in light rain is much greater than that under other weather conditions. As a result, multiple scattering effects of laser in light rain are much stronger than that under weather conditions.

Conclusion

In this paper, the Mie Scattering Theory is chosen to analyze transmission characteristics of 532-nm green laser. Moreover, the Weibull distribution is used in the raindrop size distribution

simulation to draw up the raindrop scale distribution diagram. On this basis, the relationship between the attenuation coefficient and the rainfall rate is figured out. It is concluded that laser attenuation coefficients in light rain are greater than that under other rain conditions. The result shows that the number of raindrops in light rain is more than that in the heavy rain, and laser multiple scattering effect will be more significant.

References

- [1] Sanxue Guo, Fang Wang. *The new concept of Anti-terrorism and Anti-riot weapon*. Xi'an: Xi'an Electronic and Science University press.2014
- [2] Jing Guo, *Study on attenuation characteristics of Rainfall on 532nm and 1064nm laser transmission*, J. Journal of Optics.2011.1
- [3] XiChuan Liu. Effect of non spherical Raindrops attenuation based on Laser transmission., *Infrared and Laser Engineering*.2013.1
- [4] Jian Wu, ChunPing Yang, JianBing Liu. *Theory of Light transmission in the Atmosphere*, Beijing: Beijing University of Posts and Telecommunications press.2005:4-5
- [5] MARSHALL J S, PALMER W M, The distribution of Raindrop size, *Meteorology*, 1948.5
- [6] Sekine M, Lind G. Raindrop shape limitations on Clutter cancellation Ratio using circular polarization. *IEEE Trans. Aerosp. Electron.Syst.*, 1983, 19: 631-633
- [7] Van de Hulst H C. *Light Scattering by Small Particles*, New York: Dover Publications, 1981