

attenuation of infrared laser beam propagation in the atmosphere

**DR.Sabah anwer salman,asist.teacher.Jasim mohammed khalel,
asist.teacher wedad hano abas**

College of science- University of Diyala

Abstract:

In this work, the atmospheric attenuation of laser beam due to the scattering by the atmospheric particle such as fog, mist, and haze or dust has been calculated as a function of visibility (visual range).the theoretical results show that the laser wavelength in the near infrared region $1,8\mu\text{m}$ have attenuation more than middle infrared regions $3,11\mu\text{m}$ and far infrared region $8,5\mu\text{m}$ although these wavelength have transmittance windows also these result show that, in fog condition where visibility less than $0,5\text{km}$ the atmospheric attenuation of laser beam is independence of laser wavelength . These results are obtained for horizontal path and confirmed by comparison with published data.

الخلاصة

في هذا البحث تم حساب التوهين الجوي لحزمة الليزر نتيجة استطارتها بجسيمات الجو مثل لضباب الكثيف و الخفيف والأتربة الجوية كدالة للوضوحية(مدى الرؤيا). النتائج النظرية أظهرت ان الأطوال الليزرية الواقعة في المنطقة تحت الحمراء القريبة $1,8\mu\text{m}$ تملك توهين جوي اكثر من الأطوال الليزرية الواقعة في المنطقة تحت الحمراء المتوسطة $3,11\mu\text{m}$ والبعيدة $8,5\mu\text{m}$ على الرغم من ان هذه الأطوال تمتلك نوافذ جوية.كذلك تبين في حالة الضباب الكثيف جدا حيث تكون الوضوحية اقل من $0,5\text{km}$. أن التوهين الجوي لا يعتمد على الطول الموجي بل يلزم قيم ثابتة معتمد على الوضوحية فقط . هذه النتائج حسبت للمسارات الأفقية للحزمة الليزرية وقد أظهرت هذه النتائج توافق مع البيانات والنتائج المنشورة.

1-Introduction

Knowledge on propagation infrared laser beam in the atmosphere is required for many purposes such as optical communication, earth resources remote sensing, laser guidance weapons and laser range finder.

the transmission of electromagnetic wave through the atmosphere is governed by the attenuation due to both scattering and absorption by all the atmospheric species present in the path of propagation. The atmospheric path is categorized to horizontal path (constant pressure) and slant path (changed pressure) ^{1, 2}.the absorption occurs by water vapor, carbon dioxide, ozone. nitrous oxides, carbon monoxide, nitrogen and oxygen, while the scattering is produced by gas molecules, dust, smoke, fog, and rain ^{3, 4, 5}.

2-Theoretical model

The attenuation of laser beam through the atmosphere is described By exponential Lambert law ^{6, 7, 8, 9}.

$$P_R = \frac{P_0}{e^{\int_0^R \alpha dx}} \dots\dots\dots(1)$$

Transmittance at ranger (R)

P_R Where

Laser power at range (R)

P_0

Laser power at the sources

α

Total attenuation coefficient per unit length

α

The total attenuation coefficient is given by

$$\alpha = k + S \dots\dots\dots(2)$$

Where k = absorption coefficient

S = scattering coefficient

The contribution of absorption coefficient to the total attenuation is very small special for infrared laser beam, therefore the effects of scattering dominate the total attenuation coefficient^{١,٧}.the type of scattering is determined by the size of the atmospheric particle with respect to the laser wavelength. The size of the atmospheric particle described by a dimension less number called size parameter (a) ^{٢}.

$$a \approx \frac{2r}{\lambda} \dots\dots\dots(3)$$

Where r = radius of scattering particle

λ = Laser wavelength

The general relation between wavelength and scattering coefficient is ^{٣, ٦,٧}.

$$s_{\lambda} \approx d \lambda^{-q} \dots\dots\dots(4)$$

Where d = constant parameter

q = a parameter their value depends on type of scattering

There are three type of scattering occurs in the atmosphere, these are Rayleigh, Mie and Non-selective or Geometrical scattering. Rayleigh scattering occurs when wavelength is much larger than the particle size ($\lambda \gg r$), in this kind of scattering (q) is equal to ٤ such scattering would be present even in completely clear atmosphere, because the gas molecules them selves would scatter the radiation. the effect of Rayleigh scattering on the total attenuation is very small, so it can be neglected^{٣, ٦}.

As the particle size approaches laser wavelength ($\lambda \approx r$), scattering of radiation off the larger particles becomes more dominate in the forward direction as opposed to the backward direction. this type of scattering, where the size parameter (a) varies between (١, ٦) and ١٠) such as fog, smoke, haze and dust is called Mie scattering , where the value of q is varies from (١, ٦ to ١٠) ^{٣,٦}.

The third generalized scattering occurs when the atmospheric particles are much larger than laser wavelength ($r \gg \lambda$)or size parameter grater than ١٠, the scattering is called Geometrical or Nom-selective scattering, the scattering particles are larger enough that the angular distribution of scattered radiation can be described by geometric optics .Rain

drops, snow, hail, cloud droplets and heavy fogs will geometrically laser wavelength. the scattering is called Non-selective because there is no dependence of the attenuation coefficient on laser wavelength, where the value of (q) equal zero^{r,v}.

3- Methods of calculation

According to general equation (ξ) an empirical relation often used to calculate the atmospheric attenuation in term of visibility (visual range) and wavelength this relation is ^{v, r, ξ, v}.

$$S = \frac{3.92}{v} \times \frac{0.55}{\lambda^q} \dots\dots\dots(5)$$

Where λ =wavelength in micrometer (μm)

v = visibility (visual range) in kilometer (Km) .

S = atmospheric attenuation caused by scattering.

q = the size distribution of the scattering particles

q = 1,7 for high visibility (v > 0.5 km)..... (0- a).

q = 1,3 for average visibility (1 km < v < 0.5 km)..... (0- b).

for low visibility (v < 1 km).....(0- c). $\sqrt[3]{v} q = 0.80$

The visibility (v) is defined as the path length at which transmission at 0.55 μm wavelength (where the sensitivity for the light adapted human eye peak) is 2%,this is intended to correspond to the distance at which a black object can just be discerned against the horizon sky, therefore for R = v we have τ = 0.02 According to equations (ξ and 0) the value of (q) is very important because it determines the wavelength dependence of the attenuation coefficient and the type of scattering ^{0.7, v, 1}.

A search of the literature agrees with equation (0) but the value of (q) at low visibility equation (0-c) might in error. in fact there is strong empirical data which suggests for the value of (q) when the visibility is less than (1 km).Eldridge defined three generalized type of shorter visibility weather fog for visibility less than (0.5 km) , haze for visibilities greater than(1 km) and transitional zone called mist for visibilities between (0.5 km and 1 km).these zone are based on changes in observed particle size distributions and changes

in the wavelength selectivity of measured attenuation coefficients which have mentioned previously.

Then the expression for (q) in equation (٥-c) is ^{٣,٤}

$$\begin{aligned}
 q &= 0 && \text{for fog (v < 0.05 km) (٦-a)} \\
 q &= v - 0.05 && \text{for mist (0.05 km < v < 1 km)..... (٦-b)} && q = 0.16 v \\
 + 0.34 &&& \text{for haze (1 km < v < 5 km)..... (٦-c)}
 \end{aligned}$$

Where (v) is the visibility in km unit.

Eldridge indicates that haze is primarily made of microscopic fine dust or salt or small water dropt on the order of a few tenths of a micron. fog occurs during very high relative humidity when water droplets of a few microns to a few tens of microns from over the haze particle. Mist occurs during the transition from haze to fog as the humidity increases to saturation ^{٣,٤}.

The unit that is used in this research to measure the attenuation is Decibel per unit length, from equation (٦) the Decibel unit (dB) is defined as ^{٩}

$$Q_R \approx 10 \log_{10} \frac{P_R}{P_0} \approx (10 \log_{10} e) \alpha R \approx 4.34 \alpha R \approx 4.34 Q_R$$

To make the attenuation in Decibel per unit Length multiple equation (٥) by factor (٤,٣٤) ^{٩}. Theoretically by using (VISUAL-BASIC) Program figure (٦) the atmospheric attenuation of laser beam has been calculated.

٤-Results and discussion

The decibel loss per kilometer for different visibility condition in Table (٦) are derived from the attenuation coefficient calculated using Equation (٥) From figure (٦) it can be noted that the energy that is loosing from the laser beam through the atmosphere it decrease with increasing the visibility, where the visibility represent the weather conditions, this mean there is visual range related with the weather condition specially

related with radius and distribution of the atmospheric particles the weather condition that is considered for calculation the atmospheric attenuation is a general not limited in a geographic location and the beam propagate horizontally with one layer in the atmosphere ,where this layer have same optical properties (refraction index)for all wavelength also have other properties such as pressure temperature .

It can be concluded from table (1) that the atmospheric attenuation at a given visibility value decreases with the increasing the wavelength, for example at visual range (1km) the attenuation for(1,4μm) wavelength is (9,3^dB/km) While for (4,0μm) is (4,3^ dB/km) the explain of these results essentially return to Plank law⁽⁴⁾.

$$E = h \nu = h \frac{c}{\lambda} \dots \dots \dots (7)$$

Where E = energy of photon
 ν = frequency of phonon
 c = velocity of light

According to equation (7) the energy that is carrying by the wavelength (4,0μm) essentially less than the energy that is carrying by the wavelength (1,4μm), therefore the attenuation for near infrared regions 1,4μm is more than middle infrared regions 3,9 μm and far infrared region 4,0μm although these wavelengths have transmittance windows. These results also consider as proof for Plank law.

Also from figure (5) it can be seen that, in fog condition where the visibility is less than (1,0 Km) the atmospheric attenuation take the same value for different laser wavelength because the value of (q) parameter equal zero Equation (1-a), therefore the atmospheric attenuation is independent to the wavelength.

٥-Conclusion

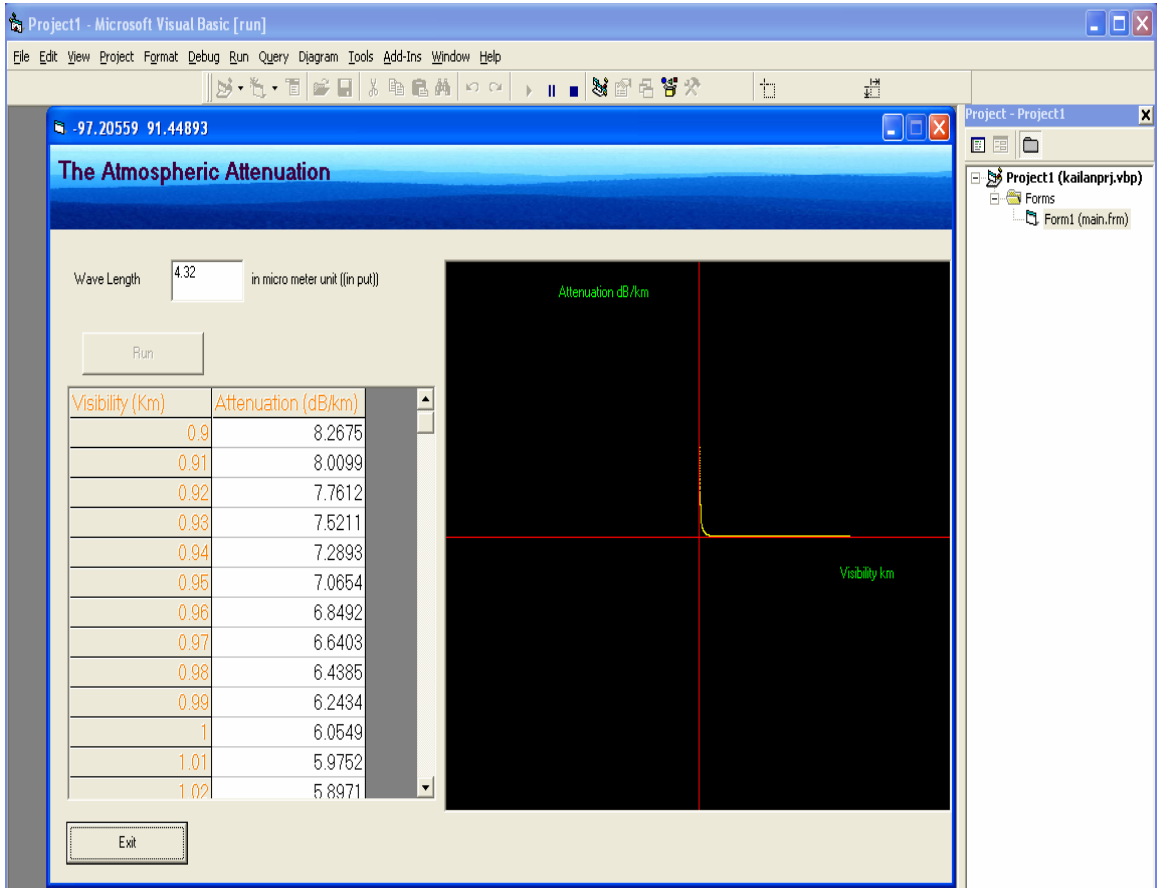
١- The contribution of absorption coefficient to the total attenuation is very small special for infrared laser beam; therefore the effects of scattering dominate the total attenuation coefficient.

٢-In fog condition where the visibility is less than (٠,٥ Km) the atmospheric attenuation take the same value for different laser wavelength, therefore the atmospheric attenuation is independent to the wavelength.

٣-By using this theoretical model the atmospheric attenuation caused by scattering can calculated for different laser wavelength and different visibility also we can calculates the atmospheric transmission for different given rang.

Table (1) A table of atmospheric attenuation in (dB/km) as a function of visibility for difference laser wavelength.

Visibility (Km)	Atmospheric attenuation(dB/Km)						Weather condition
	$\lambda=1,07$ (μm)	$\lambda=1,8$ (μm)	$\lambda=3,11$ (μm)	$\lambda=4,32$ (μm)	$\lambda=8,0$ (μm)	$\lambda=10$ (μm)	
0,1	1797,94	1797,94	1797,94	1797,94	1797,94	1797,94	fog (10-20) μm Radius
0,2	848,47	848,47	848,47	848,47	848,47	848,47	
0,3	565,65	565,65	565,65	565,65	565,65	565,65	
0,5	339,38	339,38	339,38	339,38	339,38	339,38	
0,7	256,84	256,84	256,84	256,84	256,84	256,84	
0,8	224,71	224,71	224,71	224,71	224,71	224,71	
0,9	199,79	199,79	199,79	199,79	199,79	199,79	
1	179,79	179,79	179,79	179,79	179,79	179,79	
1,5	119,86	119,86	119,86	119,86	119,86	119,86	
2	89,89	89,89	89,89	89,89	89,89	89,89	
3	69,89	69,89	69,89	69,89	69,89	69,89	
4	59,89	59,89	59,89	59,89	59,89	59,89	
5	54,89	54,89	54,89	54,89	54,89	54,89	
6	50,89	50,89	50,89	50,89	50,89	50,89	
7	47,89	47,89	47,89	47,89	47,89	47,89	
8	45,89	45,89	45,89	45,89	45,89	45,89	
9	44,89	44,89	44,89	44,89	44,89	44,89	
10	44,89	44,89	44,89	44,89	44,89	44,89	
15	40,89	40,89	40,89	40,89	40,89	40,89	
20	37,89	37,89	37,89	37,89	37,89	37,89	
30	33,89	33,89	33,89	33,89	33,89	33,89	
40	31,89	31,89	31,89	31,89	31,89	31,89	
50	30,89	30,89	30,89	30,89	30,89	30,89	
60	29,89	29,89	29,89	29,89	29,89	29,89	
70	29,89	29,89	29,89	29,89	29,89	29,89	
80	29,89	29,89	29,89	29,89	29,89	29,89	
90	29,89	29,89	29,89	29,89	29,89	29,89	
100	29,89	29,89	29,89	29,89	29,89	29,89	



Figure(1) shows the executive view of the (VISUAL-BASIC) Program to calculate the atmospheric attenuation for different laser wavelength as data input in micrometer(μm)unit the Visibility(V) in (Km)and Attenuation (S) in(dB/Km) are calculated.

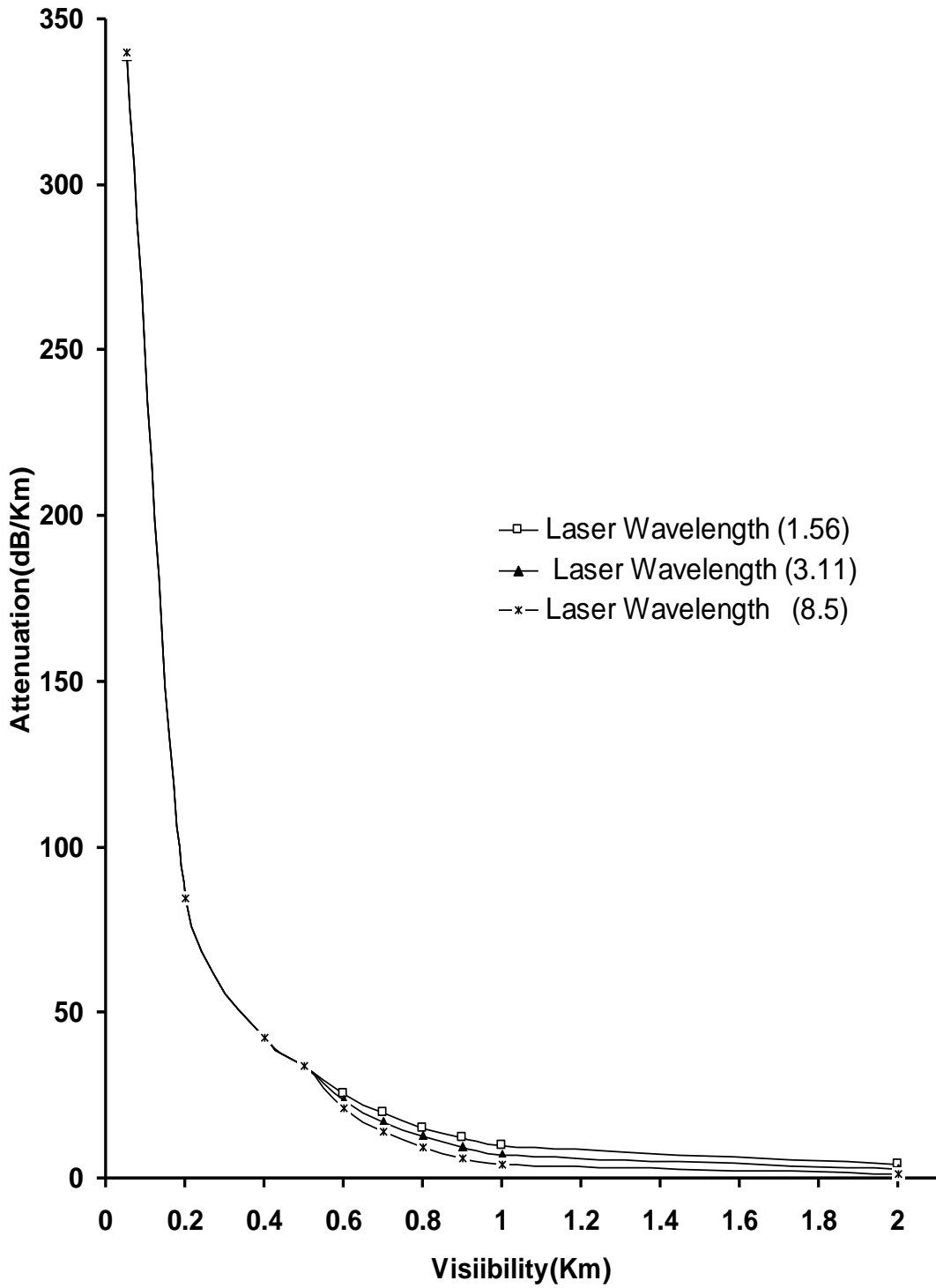


Figure (γ) Atmospheric Attenuation as a function of the Visibility for different Laser wavelength.

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