Attenuation of laser beam propagation in the atmosphere

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Abstract:

In this search I am calculated theoretical model for attenuation of laser beam due to the scattering by the atmospheric particle (fog, mist, haze and dust) as a function of visual range (visibility). the theoretical results show that the laser wavelength in the Ultraviolet region 0.337 µm have attenuation more than Visible regions, 0.6328µm and near infrared region 1.06µm, also these result show that, in fog condition where visibility is less than 0.6km, the atmospheric attenuation of laser beam is independence of laser wavelength.

1-**Introduction**

The transmittance of laser beam in atmosphere is very important process in many military and civilian applications with technique development using laser beam. During the laser transmission in the atmosphere, the laser beam suffers 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) [1,3].the absorption occurs by water vapor, carbon dioxide, ozone. Nitrous oxides, carbon monoxide, nitrogen and oxygen, while the scattering is produced by gas molecules, fog, smoke and dust[1,4]. The earth's atmosphere is surrounded by number of layers, each layer is characterized by (pressure, density, and temperature), and these properties of layers are variable with time and location .The transparency of the atmosphere for laser radiation is one of the most important parameters in the calculation of the attenuation. This is depending on the weather and the path length[2,5].

2-**Theoretical model**

The general process by which radiant flux is attenuated in passing through the atmosphere is called extinction. The transmittance of a path throught the atmosphere can be expressed by Lambert law [4,5,7].

$$T_L = e^{-\gamma L}..............(1)$$

Where T_L Transmittance through path length (L)

$$\gamma = S + a...............(2)$$

Where $\gamma =$ Total attenuation coefficient, S =scattering coefficient and a= absorption coefficient.

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 (*k*) [6].

$$K = \frac{2\pi r}{\lambda} ....(3)$$

Where r = radius of scattering particle and Laser wavelength λ =
The general relation between wavelength and scattering coefficient is [8,9].

$$S_\lambda = d / \lambda^q ....(4)$$

Where d = constant parameter and q = a parameter whose value depends on type of scattering.

There are three type of scattering occurs in the atmosphere, Rayleigh, Mie and Non-selective or Geometrical scattering. Rayleigh scattering occurs when wavelength is much larger than the particle size ($\lambda >> r$), in this kind of scattering (q) is equal to 4 such scattering would be present even in completely clear atmosphere, because the gas molecules themselves would scatter the radiation. the effect of Rayleigh scattering on the total attenuation is very small, so it can be neglected[2,4,11].

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 (*K*) varies between (0.1, 50) such as fog, smoke, haze and dust is called Mie scattering , where the value of q varies from (0 to 1.6) [3,6] .The third generalized scattering occurs when the atmospheric particles are much larger than laser wavelength ($r >> \lambda$) size parameter grater than 50, the scattering is called Geometrical or Nom-selective scattering, the scattering particles are larger enough so that the angular distribution of scattered radiation can be described by geometric optics .the Rain drops ,snow, hail, cloud droplets and heavy fogs are caused Geometrical or Non-selective scattering of 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[1].

Calculating 3-

According to general equation (4) an empirical relation often used to calculate the atmospheric attenuation in term of visibility and wavelength this relation is [9,11] .

$$S = \frac{3.91}{V}\left(\frac{0.55}{\lambda}\right)^q ....(5)$$

Where λ =wavelength in micrometer (µm),V =visual range in kilometer (Km) and q = the size distribution of the scattering particles.

q =1.6 for good visibility (V > 50km)…………. (5- a).

q =1.3 for average visibility (6km<V <50km)… (5- b).

q=0.585 for low visibility (V < 6km) $q=\sqrt[3]{V}$ *……..(5- c).*

The visibility (*V*) is defined as the path length at which transmission at 0.55µm wavelength (where the sensitivity for the light adapted human eye peak) is 2%, this is intended to correspond to the distance at *which* a block object can just be discerned against the horizon sky, therefore for R=*V* we have *T* = 2% According to equations (4 and 5) the value of (q) is very important because it determines the wavelength dependence of the attenuation coefficient and the type of scattering [4,12].

A search in literature agrees with equation (5) but the value of (q) at law visibility equation (5-c) some in error. in fact there is strong empirical data which suggests for the value of (q) when the visibility is less than (6km).Eldridge defined three generalized types of zones of shorter visibility as range , weather fog for visibility less than (0.6 km) , haze for visibilities greater than(1km) and transitional zone called mist for visibilities between (0.6 km and 1km).these zones are based on changes in observed particle size distributions and changes in the wavelength selectivity of measured attenuation coefficients which have mentioned previously[2,3,13].

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 [2,5].

The unit that is used in this research to measure the attenuation is Decibel per unit length, from equation (1) the Decibel unit (dB) is defined as [10] :

$$T_L(dB) = (10Log_{10}e)\gamma L = 4.342\gamma L = 4.342T_L........(6)$$

The attenuation by scattering in Decibel per unit Length multiply equation (5) by no. (4.342).

4-Results and discussion

For different visibility condition derived from the attenuation coefficient calculated using Equation (5) as in figure (1) it can be noted that the energy loosing from the laser beam through the atmosphere decreases with increasing the visibility, where the visibility represents the weather conditions, this means there is a visual range which is related to weather condition specially related to radius and distribution of the atmospheric particles the weather condition that is considered for calculation the atmospheric attenuation is general not limited to a geographic location and the beam propagate horizontally with one layer in the atmosphere ,where this layer have same optical properties (attenuation and turbulence) all wave length also have other properties such as pressure temperature .

It can be concluded from figure (2) that the atmospheric attenuation at a given visibility value decreases with increasing the wavelength

The energy that is carrying by the wavelength (1.06µm) is essentially less than the energy that is carrying by the wavelength (0.337µm), therefore the attenuation for Ultraviolet regions 0.337µm is more than visible regions 0.6328µm and Near infrared region 1.06µm although these wavelengths have transmittance windows. These results also agree with Plank law.

5-Conclusion

1- From figure (1)and figure(2) it can be seen that, in fog condition where the visibility is less than 0.6 Km the atmospheric attenuation take the same value for different laser wavelength because the value of (q) parameter equal zero, therefore the atmospheric attenuation is independent on wavelength.

2- In general the attenuation of the atmosphere increases when the visibility decreases and the attenuation of the atmosphere decreases visibility when the visibility increases.

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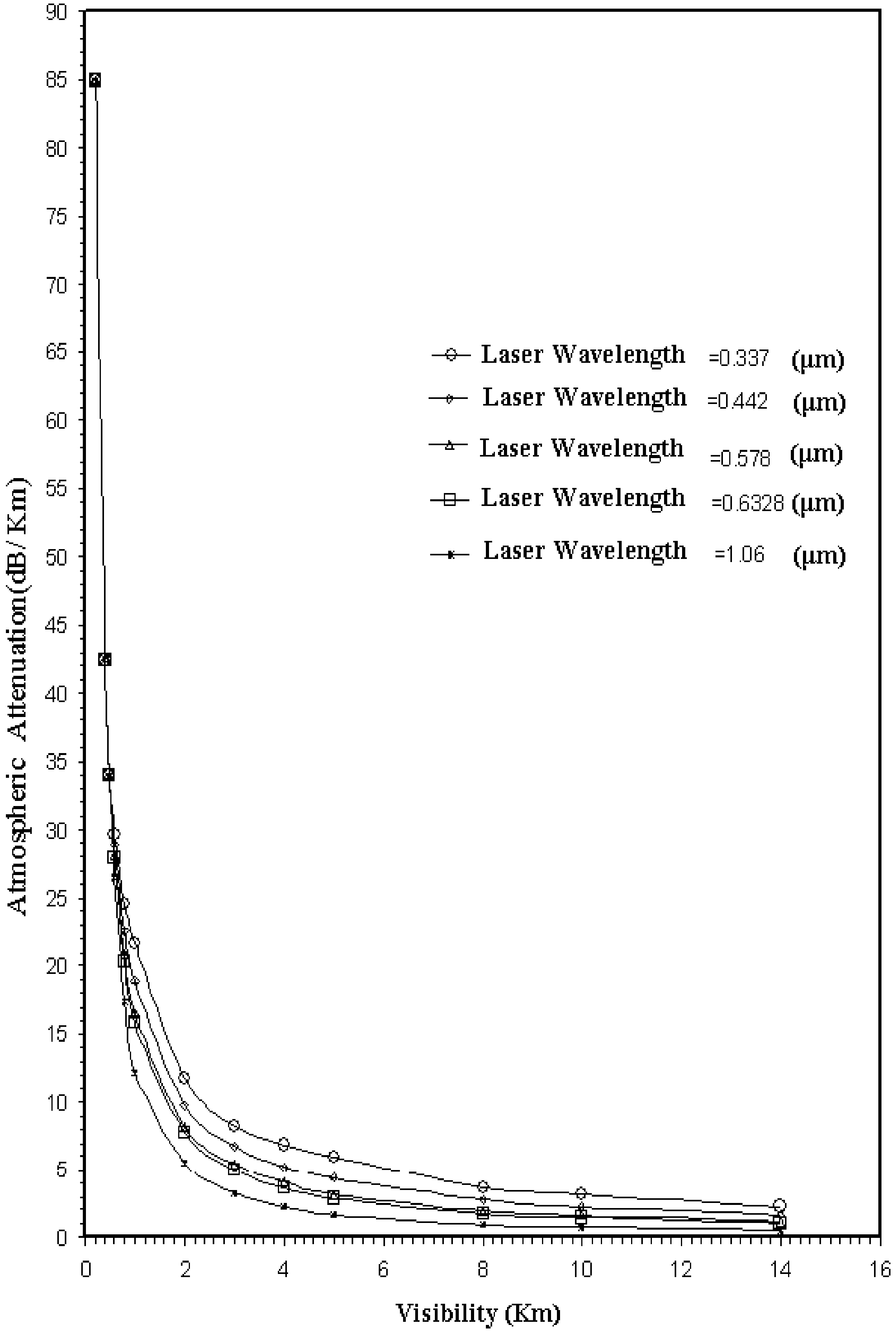
Atmospheric Attenuation (dB/ Km)
Visibility (Km)
Laser Wavelength =0.337 (µm)
Laser Wavelength =0.442 (µm)
Laser Wavelength =0.578 (µm)
Laser Wavelength =0.6328 (µm)
Laser Wavelength =1.06 (µm)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
2
4
6
8
10
12
14
16

Figure (1) Atmospheric attenuation as a function of the visibility for different laser wavelength.

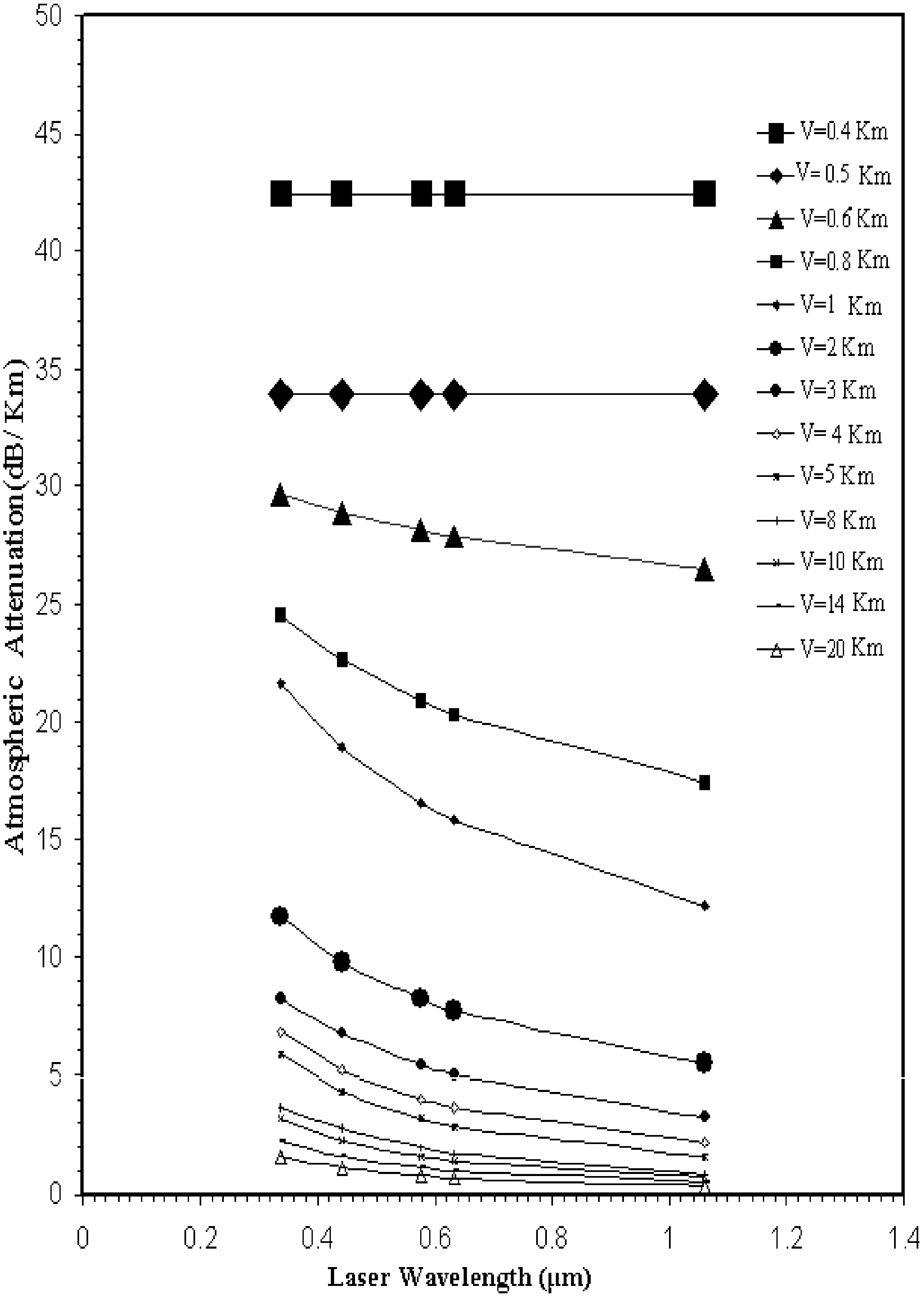

Figure (2) Atmospheric attenuation as a function of laser wavelength for different visibility(*V*) in kilometer unit (Km) .

الخلاصة:

لقد تم في هذا البحث حساب نتائج النموذج النظري لتوهين حزمة الليزر الناتجة من تاثيرالاستطارة لجسيمات الجو مثل الضباب الكثيف و الخفيف والأتربة الجوية كدالة لمدى الرؤيا (الوضوحية). النتائج النظرية أظهرت إن الأطوال الموجية الليزرية الواقعة في المنطقة الفوق البنفسجية 0.337µm تملك توهين جوي اقل من الأطوال الموجية الليزرية الواقعة في المنطقة المرئية µm 0.6328 و المنطقة تحت الحمراء القريبة µm 1.06 .كذالك تبين ان حالة الضباب الكثيف جدا حيث تكون الوضوحية اقل من 0.6km فان التوهين الجوي لا يعتمد على الطول ألموجي بل يلازم قيم ثابتة معتمد على الوضوحية فقط .