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Investigation of intensity laser effects on environment

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Abstract: In this paper different types of weather conditions which effect laser beam quality are being study. atmospheric conditions such as rain, snow, fog and dust are discussed. Atmospheric turbulence effect on size and intensity of laser beam is described and background optical power relations and received power by receiver are presented. Ground target reflection coefficient and related charts are presented.
Keywords: laser, Atmosphere, Scattering, turbulence,

1- Introduction

In research, especially in the military field, extensive studies have been conducted on guided laser equipment. Use of laser-guided equipment began in America Air Force during the Vietnam War since the 1970s. The first advantage of this type of weapons was confirmed in this war proved in precision destroying targets with relatively small dimensions but with high importance. Today, laser weapons are used much wider for operations against enemy targets armor and protection. The biggest advantage of this type of weaponry is their high precision that can destroy the precise goals with the least amount of ammunition. Another advantage of using these weapons is the possibility of targeting a point precisely for consecutive times that is very efficient to eliminate armor targets. In recent years, military studies and the correct choice of materials for the manufacture of tracker systems pay special attention to laser detectors. Before transmitting a laser beam inside the environment, it is important to identify the effects of the environment on the beam. Molecules and particles such as dust, fog, smoke, steam, and aerosols ,have significant effects on the dispersion, reflection and absorption of laser beams, which themselves contribute to the degradation, deviation, and reduction of laser beam coherence. In this paper, the effects of the environment on the laser beam and the ways to reduce these effects are examined.

2- Discussions

Atmospheric obscurants reduce the performance of sensors by reducing the signal radiation reaching the sensor because of reduced atmosphere transmittance in the sensor wave length response region, increasing noise at the sensor due to scattering of atmosphering radiation or system illuminator energy into the sensor and reducing the signal – to – noise ratio through turbulence induced wave – front degradation.
The three curves indicate a tropical atmosphere with high water vapor content, a subarctic atmosphere, which has a low water vapor content, and a typical us or midlatitude atmosphere, which has a moderate contant . These curves illustrate the effect of water vapor contant on thermal transmittance.
Extinction is defined as the reduction, or attenuation of radiation passing through atmosphere.
Extinction comprise two process: absorption of energy and scattering of energy. In absorption, a photon of radiation is absorbed by an atmosphere molecular or an aerosol particle. In scattering , the direction of the incident radiation is changed by collisions with atmospheric molecular or aerosol particle. Absorption usually dominates scattering at IR and mmw wave length. Scattering is the major factor in visible extinction but may also be important at IR wave length .

Scattering effectiveness is given by the scattering efficiency Q (n , r) which is ratio of the effective scattering cross of a particle of radius r to its geometric cross section as[1, 2] :

$$Q(\lambda, r) = \frac{\sigma_s}{\pi r^2} = \frac{2}{r^2}\int_0^{\pi} \sigma_s(\theta)\sin\theta d\theta \qquad (1)$$

Where
r = particle radius , m
σ = angular scattering cross section , m/sr
θ = scattering angle , rad
If the particle size is much smaller than the radiation wave length , Rayliegh scattering results , and scattering efficiency simplifies to the expression [1] :

$$Q(\lambda, r) = \frac{8}{3}(2\pi)^4 \frac{r^4[n(\lambda)^2 - 1]^2}{\lambda^4[n(\lambda)^2 + 2]^2} \qquad)2 ($$

Where
n(λ) = real part of index of refraction ,r = particle radius , m .
Particale size for several common obscurants are given in tables1 and 2.If the particle size is much larger than the radiation wave length,scattering efficiencycalculated by geometricalscattering.

Table 1the effect of the particles on the order dispersion wave length [1]

Radius of particle	Distribution type	Effect
less than λ/10	Rayleigh scattering	Symmetric distribution
more than λ/10	Mie scattering	Most distribution
about λ/4	Mie scattering	Most scatting forward
more than λ	Mie scattering	All scatting forward
more than 10 λ	Light scatting geometry	Refraction , reflection , diffraction

Table 2 particle size distribution and the effect of atmospheric turbulence[1]

Particle size	**Diameter of particle (μm)**	**vision waves**	**Ir waves**	**mm waves**
Atmosphere Molecule	10^{-4}	Rayleigh scattering	Rayleigh scattering	Rayleigh scattering
Haze	10^{-2} to 10^{-1}	Rayleigh and Mie scattering	Rayleigh scattering	Rayleigh scattering
Fog	0.5 t0 100	Mie and geometric scattering	Mie scattering	Rayleigh scattering
Cloud	2 to 200	Mie and geometric scattering	Mie scattering	Rayleigh scattering
Rain	10^{2} to 10^{4}	Geometric scattering	Geometric scattering	Mie scattering
Show	5×10^3 to 5×10^5	Geometric scattering	Geometric scattering	Mie and geometric scattering
Smoke	1	Mie and geometric scattering	Mie scattering	Rayleigh scattering
Dust	1 to 100	Mie and geometric scattering	Mie scattering	Rayleigh scattering

According to the table 2 , types of atmospheric particles (steam, aerosols , rain, snow ,…) have different scattering relations.
Steam

The following equation shows the atmosphere transmittance coefficient for steam and molecular particles[1].

$$T_m(\lambda) = e^{-Y_m(\lambda)R} \qquad (3)$$

Where
T_m = atmosphere transmittance coefficient for steam and molecular
= steam and molecular attenuation coefficient .Y_m
R = Path length
The average value of γ for low humidity (lower water vaper than 3.5 g /m^3) in visible spectrum is between 0.4 and 0.7 and for high humidity (water vaper more than 14 g /m^3) is about 0.02 .

In the near – infrared range (between 0.7 and 1.1) for low humidity the average value of γ is about 0.02 and for high humidity is about 0.03 .
The water vapor atmosphere transmittance coefficient within 3 to 5 μm is specifid in table 3and within 8 to 12 μm in table 4.
Also according to table 5, the attenuation coefficient for 10.591 wave length and mmw in different humidities.

Table 3 Transmission coefficient for water vapor in the atmosphere of moisture and different distances ranging from **3-5 μm**[1]

Transmission coefficient for water vapor in the atmosphere of moisture $T_m(\lambda)$							
The moisture content	Temperature (°C)	**Along the way in terms km**					
		1	3	5	7	10	**15**
10	0	0.77	0.68	0.62	0.58	0.53	**0.47**
	10	0.74	0.61	0.58	0.53	0.48	**0.42**
	20	0.71	0.60	0.53	0.49	0.44	**0.38**
	30	0.67	0.55	0.48	0.44	0.39	**0.33**
40	0	0.70	0.58	0.51	0.47	0.41	**0.35**
	10	0.66	0.53	46	0.41	0.36	**0.30**
	20	0.61	0.47	0.40	0.35	0.30	**0.24**
	30	0.56	0.42	0.35	0.30	0.25	**0.19**
70	0	0.66	0.53	0.46	0.41	0.36	**0.30**
	10	0.61	0.47	0.40	0.35	0.30	**0.24**
	20	0.56	0.41	0.34	0.29	0.24	**0.18**
	30	0.50	0.36	0.28	0.23	0.18	**0.13**
90	0	0.64	0.51	0.44	0.39	0.33	**0.27**
	10	0.59	0.45	0.37	0.33	0.27	**0.21**
	20	0.53	0.39	0.31	0.26	0.21	**0.15**
	30	0.48	0.33	0.25	0.20	0.15	**0.10**

Table 4 Transmission coefficient for water vapor in the atmosphere of moisture and different distances ranging from **8-12** μm[1]

Transmission coefficient for water vapor in the atmosphere of moisture $T_m(\lambda)$							
The moisture content	Temperature (℃)	**Along the way in terms km**					
		1	3	5	7	10	**15**
10	0	0.97	0.95	0.93	0.91	0.89	**0.86**
	10	0.97	0.93	0.91	0.89	0.86	**0.82**
	20	0.95	0.91	0.87	0.85	0.81	**0.76**
	30	0.94	0.87	0.82	0.78	0.72	**0.65**
40	0	0.95	0.89	0.86	0.82	0.78	**0.72**
	10	0.92	0.84	0.77	0.72	0.65	**0.55**
	20	0.87	0.73	0.62	0.54	0.43	**0.31**
	30	0.78	0.54	0.39	0.28	0.18	**0.09**
70	0	0.93	0.84	0.78	0.73	0.66	**0.56**
	10	0.87	0.73	0.62	0.53	0.42	**0.30**
	20	0.77	0.52	0.36	0.26	0.15	**0.07**
	30	0.59	0.25	0.11	0.05	0.02	**0.0**
9	0	0.91	0.80	0.72	0.66	0.57	**0.46**
	10	0.83	0.64	0.51	0.41	0.30	**0.18**
	20	0.69	0.39	0.023	0.13	0.06	**0.02**
	30	0.46	0.12	0.04	0.01	0.0	**0.0**

Table 5 Molecules attenuation coefficient for wavelength 10.591 μm and millimeter waves atdifferent Humidities[1]

Absolute humidityIn terms of g/m^3	Attenuation coefficientΥ_m**In terms of** Km^{-1}		
	10.591 μm	35 GHz	94 GHz
1	0.083	0.018	0.025
3	0.091	0.021	0.043
5	0.109	0.024	0.067
10	0.185	0.032	0.108
15	0.311	0.041	0.154
20	0.383	0.049	0.201

Aerosol (fog , cloud, dust)
The equation below shows the atmosphere transmittance coefficient for aerosols[1]:

$$T_a(\lambda) = e^{-\Upsilon_a(\lambda)R}$$

where$T_a$atmosphere transmittance coefficient $\Upsilon_a$reduce coefficient of aerosols and R= path length.The avearage ofΥ_a in visible spectrum (between 0.4 to 0.7) is:

$$\Upsilon_a(0.4 - 0.7\mu m) = 3.912/V \qquad (5)$$

Where V is visible distance in km
Visible distance is defined as the distance which you can diagnose an object properly by the contrast of l against background by the contrast of 0.02[1]
In table 6 visibility is provided for different reigons.

Table 6 Visible distances for different regions[3]

Dense dust	**0 to 50 meter**
Thick dust	**50 to 200 meter**
The average dust	**200 to 500 meter**
Dust weak	**500 to 1000 meter**
Low dust	**1000 to 2000 meter**
Fog	**2000 to 4000 meter**
May the poor	**4000 to 10000 meter**
clean Air	**10000 to 20000 meter**
Very clean air	**20000 to 50000 meter**
Ultra-clean air	**more than 50000 meter**

in IR area for the yag laser:two values will be obtained for aerosols attenuation coefficient one for visible distance more than 0.6 km which is equal to[1]:

$$\Upsilon_{a1}(1.06\mu m) = 10^{[-0.136+1.16 log\,(3.912/V)]} \qquad (6)$$

And for a visible distance less than 0.6 km and equal to 0.6 km[1]:

$$\Upsilon_{a2}(1.06\mu m) = 3.912/V \qquad (7)$$

In near-IR range(between 0.7 to 1.1)the average value of Υ_a is equal to[1]:

$$\Upsilon_a(0.7 - 1.1\mu m) = 0.6(3.912/V) \qquad (8)$$

Table7 shows the attenuation coefficient for other wavelength.

Table 7 Attenuation coefficient of suspended particles in the air for wavelength10.591 , 8-12 μm , 3-5 μm[1]

Particle size	**Attenuation coefficient $\Upsilon_a$in terms of Km^{-1}**		
	10.591 μm	8-12 μm	3-5 μm
May city			
Visibility to 2 km	0.16	0.18	0.29
Visibility to 5 km	0.06	0.07	0.11
Visibility to 10 km	0.03	0.04	0.6
Visibility to 15 km	0.02	0.02	0.04
May incident			
Visibility to 0.5 km	1.7	2.4	10.1
Visibility to 1 km	0.9	1.2	5.1
May rose			
Visibility to 0.5 km	8.9	9.0	8.4
Visibility to 1 km	4.5	4.5	4.2

Radiation fog forms when the weather cools down until the dew point and advection fog forms when vertical air mixture with different temperatures manufactures until the dew point. In these two types the size of fog particle are different.

Rain:
The following equation defines the atmosphere transmittance coefficient for the precipitation in the air[1].

$T_p(\lambda) = e^{-Y_p(\lambda)R}$ (9)

Where
.T_p= the atmosphere transmittance coefficient for the precipitation in the air
.Y_p= the precipitation attenuation coefficient
R=path length
The average value of Y_p (in visible spectrum range to thermal wavelength) determines based on the amount of rainfall for three different types of rainfall.
For the drizzle we have[1]:

$Y_{prd}(\text{Visible} - \text{Thermal}) = 0.51r^{0.63}$ (10)

For the widespread we have:

$Y_{prw}(\text{Visible} - \text{Thermal}) = 0.36r^{0.63}$ (11)

And for the thounderstorm we have :

$Y_{prt}(\text{Visible} - \text{Thermal}) = 0.16r^{0.63}$ (12)

Where r = amount of rainfall (mm per hour(mmph))

Table 8 Precipitation

Rainfall intensity	**Annual rate**
Heavy	More than 7.7 mm/h
Average	2.5 to 7.7 mm/h
Light	Less than 2.5 mm/h

Snowfall:
The atmosphere transmittance coefficient equation for both rainfall and snowfall are the same. The only difference is the attenuation coefficient . the snowfall attenuation coefficient depends on visible distance and equals to[1]:

$Y_{ps}(\text{Visible} - \text{Thermal}) = {}^{3.912}/_{V}$ (13)

Dust:
The following equation defines the atmosphere transmittance coefficient for dust in the air[1].

$T_d(\lambda) = e^{-\alpha_d(\lambda)Cl}$ (14)

Where
.T_d = atmosphere transmittance coefficient for dust in the air
..α_d= attenuation coefficient of dust in the air
And cl= path length density by g/m^2
Cl achieves from multiplication of upload mass by path length R generally for the a we could write[1]

$\alpha_d(\lambda) = \ll \frac{Q\sigma}{M} \gg$ (15)

Where:
σ =cross-sectional area of particle
Q= the dispersion coefficient
M=mass of the particle
The internal bracket is identifier of solid angle average and the external bracket is the identifier of mass distribution average of the particle. For the cl we have:

$Cl = \int_{r_1}^{r_2} C(r)dl$ (16)

Where

$C(r)$= density at r
. dl = longitudinal element of the doped area
= length of the doped area $r_2 - r_1$
the table 9 shows the dust attenuation coefficient for different wavelength

Table 9 Dust in the air attenuation coefficient for different wavelengths[1]

Rainfall intensity	**Annual rate**
Heavy	More than 7.7 mm/h
Average	2.5 to 7.7 mm/h
Light	Less than 2.5 mm/h

Table 10 shows the masses of different dusts for visible wavelength where visible distance is certain in it.

Table 10 Mass loading of dust visible for different distances[1]

Visible distance , Km	**Mass loading , g/m^3**
0.2	1.1×10^{-1}
0.47	6.9×10^{-2}
1	2.1×10^{-2}
3.2	5.2×10^{-3}
8	2×10^{-3}

Smoke:
The following equation defines the atmosphere transmittance coefficient for smoke in the air[1]:

$$T_s(\lambda) = e^{-\alpha_s(\lambda)Cl} \qquad (16)$$

Where
T_s = atmosphere transmittance coefficient for smoke in the air
.α_s = attenuation coefficient of smoke in the air,g/m^2
And cl = path length of density, g/m^2
Cl also defines according to the equation (17)

Table11 shows the amount of attenuation coefficient of types of smoke for different wavelength

Table 11 Smoke attenuation coefficient obtained from a variety of sources, to differentwavelengths[1]

Smoke sources	Attenuation coefficient smoke						
	wavelength in terms of micrometer						
	0.4 – 0.7	0.7 – 1.2	1.06	3-5	8-12	10.6	35.94 GHz
Fuel evaporates into mechanical	6.58	4.59	3.48	0.25	0.02	0.02	0.001
Spray fuel into diesel engines	5.65	4.08	3.25	0.25	0.03	0.03	0.001

Burning phosphorus	4.05	1.77	1.37	0.29	0.83	0.38	0.001
Burning zinc compounds	3.66	2.67	2.28	]0.19	0.04	0.03	0.001
Coal	6.00	3.50	2.000	0.23	0.05	0.06	0.001

According to the equation 17we could calculate the amount of cl so that l is the length of infected area .then due to the equation16 we could calculate the atmosphere transmittance coefficient for smoke for the all of atmosphere transmittance coefficient in the absence of precipitation we have:

$T(\lambda) = \mathrm{T}_m(\lambda)\mathrm{T}_a(\lambda)\mathrm{T}_s(\lambda)\mathrm{T}_d(\lambda)(17)$

And in presence of snowfall or rainfall we have:

$$T(\lambda) = \mathrm{T}_m(\lambda)\mathrm{T}_p(\lambda)\mathrm{T}_s(\lambda)\mathrm{T}_d(\lambda) \qquad (18)$$

Light turbulence

The atmospheric turbulence reduces by wavelength enhancement. Atmospheric turbulence causes beam extension beam divagation flashing and fluctuataion in the brightness of the beam[4].

These effect will be describe by radius of beam displacement of the center of beam compatibility or confliction of radiation of the beam.

The scintillation effect causes the reduction of pendulous power average at the receiver aperture. Movement of picture or the blur of the caused turbulence describe by optic function (coherence length) and also wavefront tilt.

The atmospheric turbulence could be considered as a compound of cell with different size and refractive index. These cells move within the beam and cause the effect which is explained at the above. Assuming still and freezed atmosphere the speed and direction of this uniform movement determines by the wind average speed. Based on the size of dominant cell and beam diameter the turbulence cells cause the beam scattering in different direction. When size of the cell is smaller than the beam diameter refraction and diffraction happens. The beam radiation figure turns into a small ray and the dark area results of interference of wavefront refraction and diffraction (flicker). Based on the turbulence power ratio each one of the two cases of the above may be observed singly or together. Strehl is the ratio of the average of radiation on the axis with turbulence to the average of radiation on the axis without turbulence .so that the ratio of the beam diameter with turbulence to the beam without turbulence is equal to:

For the long term turbulence cases we have[1] :

$$S_l = \left[1 + \left(D/r_0\right)^2\right]^{-1} \qquad (19)$$

And for the short term turbulence if $\left(D/r_0\right) \le 3$:

$$S_{s1} = \left[1 + 0.182\left(D/r_0\right)^2\right]^{-1} \qquad (20)$$

And if $\left(D/r_0\right) > 3$:

$$S_{s2} = \left[1 + \left(D/r_0\right)^2 - 1.18\left(D/r_0\right)^{5/3}\right]^{-1} \qquad (21)$$

Where

D= effective diameter of the laser aperture

.S_l= ratio of the long term strehl

.S_s= ratio of the short term strehl

And r_0= coherence length

If the turbulence is uniform we have:

$$r_0 = 0.3325(10^{-6}\lambda)^{6/5}(10^3 C_n^2 R)^{-3/5} \qquad (22)$$

Where C_n^2= constant of the refraction index by $m^{-2/3}$

The amount of C_n^2 changes between 10^{-14} for the weak turbulence $6 * 10^{-14}$ for the medium turbulence and $6 * 10^{-13}$ for hard turbulence

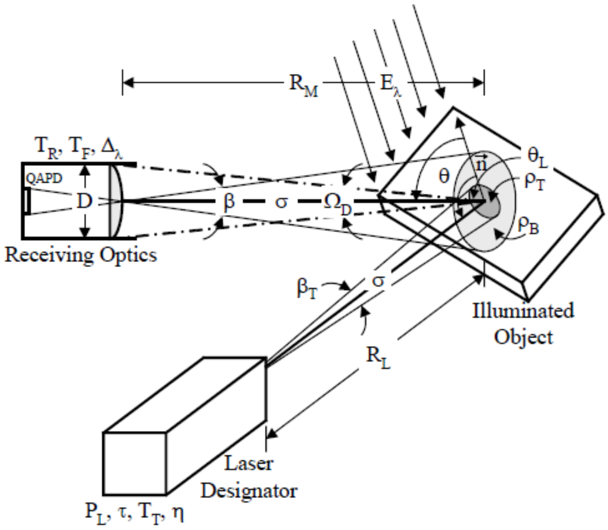
For the non-uniform turbulence this effect is strong the flicker effect due to atmosphere is estimated by the following equation

$\sigma_I^2 = 1.24C_n{}^2\left({}^{2\pi}/_{\lambda}\right)^{7/6}(10^3R)^{11/6}$ (23)

In the spread range or hard turbulence the amount of σ_I^2 wont be more than 0.5 sigma is by w for the consubtatial turbulence the amount of σ_x^2variance of the movement of the center of the picture is equal to:
$\sigma_x^2 = 1.093C_n{}^2F^2D^{-1/3}10^3R$ (24)
Where f= focal length of the receiver

The reflection coefficient of ground targets
At first reflection coefficient is reviewed for very important ground targets. Generally natural targets are divided to 5 total categories which three categories of water cloud and snow due to close nature are mentioned in one[5,6].
1- Agricultural land trees bushes and meadows
2- Ground
3- Rocks
4- Water cloud and snow
5- Metals

Received power
To determination of the most range of object location and tracing the lighten object by the laser pulse first of all it's necessary to find the light level in optical receiver sensitive position.
It's specified as well that the angel measurement error is highly dependent to noise signal ratio in output receiver ring.
In more analysis according to table 1-7 geometric characteristic of the laser, the lighten object and the optical receiver are in use to specify the optical power level at the optical reciver input [7].



In analysis, in order to generalize, it's assumed that laser and optical receiver are placed in different places.
Analysis of the power level of the background and reflected optical signal of laser behaives according to the main known equation which is radioscopy. For the background and object it's assumed that scattered reflections are reflected of the Lamberty surfaces.
Also it's assumed that all of the laser beam is on the object which is lighten by laser.
Background power
Background optical power which receives from a optical receiver sensitive to location at entrance is equal to [7] :
$P_B = L_\lambda G T_R T_F T_{at}$ (25)
Where

.L_λ=son radiance spectrum
G= geometric factor
.T_R=transference coefficient of optical receiver
.T_F=transference coefficient of optical filter
And T_{at}=atmosphere transference coefficient
G the geometric factor is obtained from two small area radiative exchange factor and equals to:
$G = \frac{A_D COS\Theta . A_R COS\Theta_{po}}{R_M^2}$ (26)
Where
.A_D= Quad detector footprint area in background
.$A_R COS\Theta_{po}$= The effective area of the photoreceptor
. ϴ = The angle between the vector perpendicular to the surface of the object and filed lines between the object and the receiver
.Θ_{po}= The angle between the vector perpendicular to the surface receptor filed with the line between the object and the receiver
.R_M= The distance between the object and the photoreceptor
In cases where tracking and positioning is good, The photoreceptor is always face to the object so $\Theta_{po} = 0$
For the whole radiance of the sunL_λ which caused by a diffuse reflector we have:
$T_{at} = e^{-\Upsilon R_M}$ (27)

Where
= the whole of the sun .E_λ
And.ρ_B= background reflect
The amount of E_λ per wavelength can be obtained from standard charts
.T_{at} atmospheric transfer coefficient is obtained from the following relationship comes to
$T_{at} = e^{-\Upsilon R_M}$ (28)
Where
. Υ=Atmospheric extinction coefficient.
The back ground power that obtained from equation(25),when combined with equations (26) and (27) has to be obtained as follows.
Where
The whole bandwidth Optical Filter.Δ_λ=
. β= photoreceptor visibility range
Diameter optical receiver.D_{po} =

Signal power

P_S the optical signal received by the laser radiation reflected from the object is lightened with a laser when the laser beam cross-sectional area of the object is smaller than, equals to:
$P_S = L_T A_T \Omega_D T_R T_F e^{-\Upsilon R_M} COS\Theta$ (29)
Where
. .L_T=Spectrum reflected from the object
.A_T=The area of the laser spot on the object
And Ω_D in accordance with Figure 3-7 angle created by the opening of an optical receiver
.L_T spectrum is [7-9]
$L_T = \frac{4P_L T_T \eta \rho_T e^{-\Upsilon R_L} COS\Theta_L}{\pi^2 \beta_T^2 R_L^2}$ (30)

Where
. P_L= peak power laser
.T_T=transmission coefficient of light
η=efficiency of collection optical transmission
.ρ_T=target reflection coefficient
.Θ_L=angle between the vector perpendicular to the surface with a laser beam
.β_T=divergence angle of the laser beam

and R_L=distance between the laser and the object
.A_T area of the laser spot on the object of value follow below

$$A_T = \frac{\pi R_L^2 \beta_T^2}{4COS\Theta_L} \qquad (31)$$

And for Ω_D angle we have:

$$\Omega_D \approx \frac{\pi {D_{po}}^2}{4R_M^2} \qquad (32)$$

By combining equations (31) to (33) with equation (30), we finally have for the P_S

$$P_S = \frac{{D_{po}}^2}{4R_M^2} P_L \rho_T T_T \eta T_R T_F e^{-\Upsilon(R_L+R_M)} COS\Theta \qquad (33)$$

Conclusion

According to the formula of laser attenuation by atmospheric conditions such as temperature, humidity, dust, rain, snow polished and smoke and ... which are dependent to the laser wavelength and the distance and the light intensity in order to minimize the laser must:

1- reduse the target distance
2-increase the incident laser beam intensity
3-increaase the Selective laser wavelength because the more higher frequency, the more attenuation efficiency and Conversely is the same situation
4- The purpose of reflecting surface so that the reflection coefficient is higher, For example, hitting a building is better that the laser to hit on smooth surfaces such as metallic windows.

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