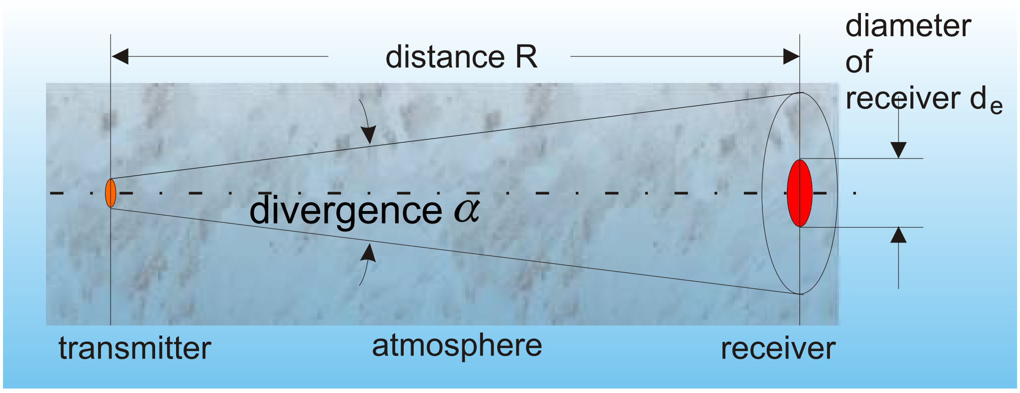
Theoretical background of FSO

The atmosphere is never homogenous. Areas of different temperatures and wind cause turbulences influencing the beam and disturbing its direct way between the terminals. The mixture of water steam, rain, dust, fog and small particles in the air like smoke has further disturbing effects on the transmission. Reflections and distractions are the consequences which may interrupt the transmission in excess.

All this effects take place everywhere and at any time when light carries data through the atmosphere. Three issues are important: geometrical attenuation, scintillation as well as molecular attenuation and scatter.

Geometrical attenuation

Only a fraction of the light coming from the transmitter reaches the receiver. A significant loss is the result.



Picture 14: Geometrical attenuation

$$a_{geom} = 20 \cdot \log\left(\frac{\alpha \cdot R}{d_e}\right) dB$$

[eq. 1]

The distance R given in meter, the divergence a of the outgoing light beam in radiant and the diameter d_e of the receiver also in meter.

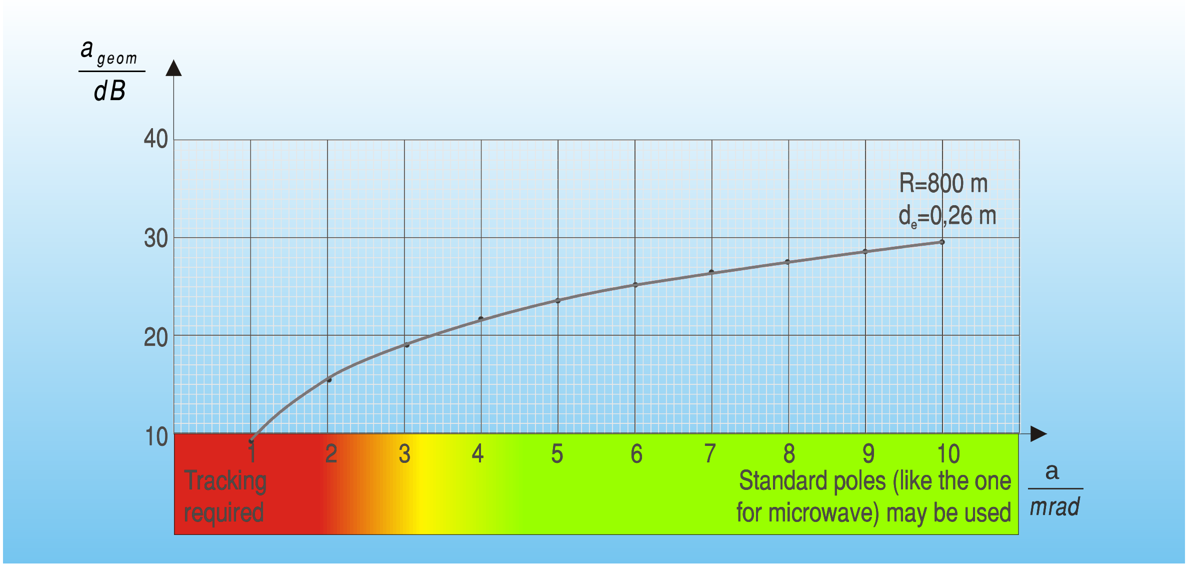
a is typically chosen between 0.5 and 15 mrad. Note that 17 mrad is equal to 1 degree and 1 mrad means opening of the beam of 1 meter per 1000 meter.

Wind and thermal expansion from sun radiation lead to very small movements of buildings, which are not detectable for the naked human eye. For divergences below 2 mrad these movements are very critical, because the footprint of the beam at the far end does not meet the receiver. Instable operation of the link can be the result from

these movements of building and poles on which terminals are installed. When the same poles as for microwave systems are to be used, CBL recommends divergences of minimum 5 mrad or internal tracking systems.

An increase of the receiver's diameter d_e helps to decrease the geometrical attenuation. Normally d_e is between 0.2 and 0.3 m. This seems to be an optimum due to the size of the terminals.

Each doubling of the divergence results in additional 6 dB geometrical attenuation.



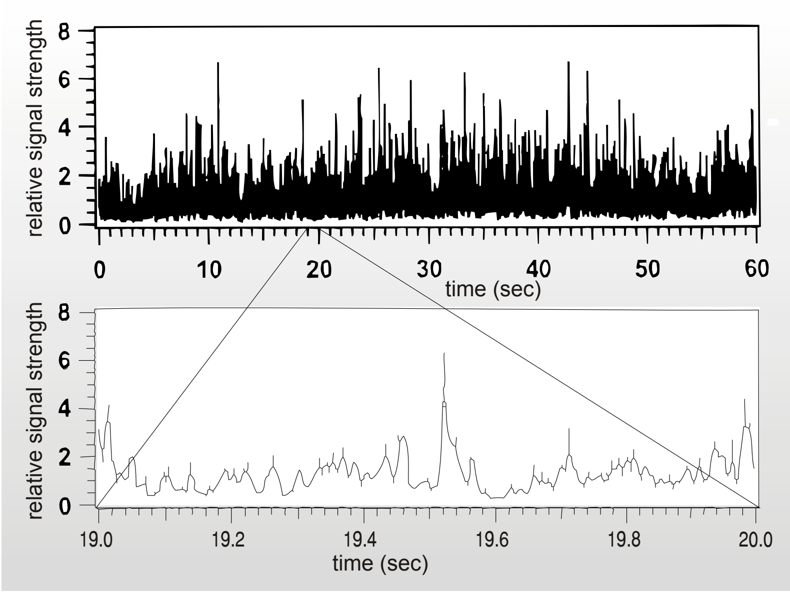
Picture 15: Geometrical attenuation a_{geom} versus divergence a

Conclusion: *Between 15 and 30 dB geometrical attenuation has to be calculated for a standard optical link running over several hundred meters with an aperture of 0.26 m diameter.*

Scintillation

If modulated light passes air regions of different temperature, there is a permanent effect of scintillation as it can be observed under starlight in a clear night. The result is a noise modulation of the detected optical signal. Picture 16 shows this effect. The noise spectrum reaches into the kHz-range and the designer has to be very attentive that the signal will not be converted to jitter in later steps of the processing unit. One way to beat this scintillation effect is to use large receiver apertures. A collector aperture which is larger than a small one provides an averaging at each lens. Another way to

reduce the effects of scintillation is to use multiple transmitters also with big apertures. Each of them takes a slightly different path through the atmosphere. This contributes to an averaging effect as well. LaserLinks uses both methodes: large aperture and multibeam technology with four transmitters.



Picture 16: Scintillation - detected noise modulation of light at the receiver

Conclusion: *To cope with scintillation, 2 dB per km hop length should be considered. This is independent of the geometrical attenuation.*

Molecular attenuation and scatter

Air consists of a lot of different gases, steam, dust particles ect. These small parts absorb energy of the light depending on its wavelength. Free space systems work usually at wavelengths of 780..900 nm or in the 1550 nm band.

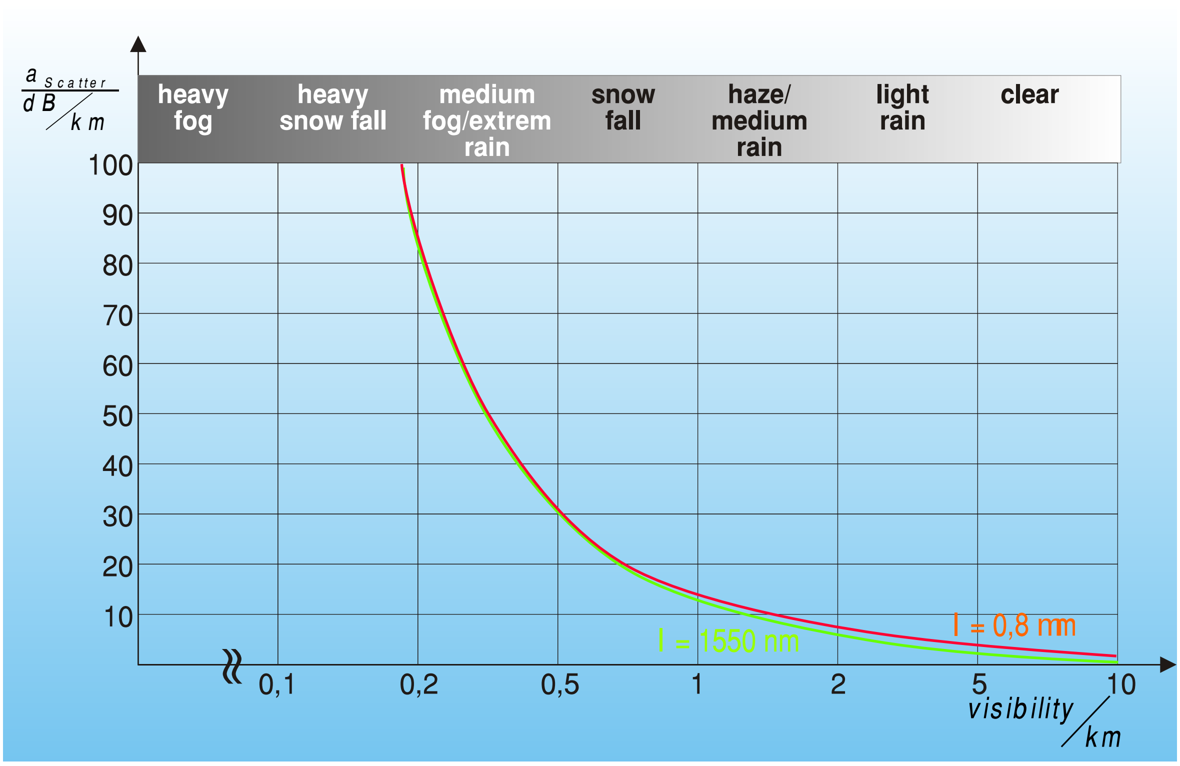
Numerous experiments lead to the following empirically determined equation:

$$a_{scatter} = \frac{17}{S/km} \cdot \left(\frac{0.55}{\lambda/\mu m} \right)^{0.195 \cdot S/km} \frac{dB}{km} \qquad \text{[eq. 2]}$$

The result for the scatter attenuation depends on the visibility S in km and the wavelength l given in mm. Visibility S is that distance within which the naked eye can still recognize larger buildings. If mist or fog is in the atmosphere, visibility decreases. Equation 2 delivers:

Weather		Fog		Medium Fog		Haze		Clear	
				extreme rain up to 180 mm/h, hail strom	rain with 100 mm/h, medium snow fall, light fog	medium rain up to 45 mm/h, light snow fall, mist	light to medium rain		
Visibility in km		0,05	0,2	0,5	1	2	4	10	23
Attenuation in	dB/km @800 nm	345	88	33	16	7,5	3.1	1.05	0.5
	dB/km @1550 nm	345	87	34	10.5	4.5	2.1	0.4	0,2

The effect of the wavelength dependend attenuation is not significant for the near infrared range between 750 and 1550 nm. 1550 nm offers advantages only in clear weather, when it is not necessary.



Picture 17: Weather dependent attenuation and the scatter attenuation versus visibility

Conclusion: *These extreme differences are the reason why FSO <u>cannot</u> work under all weather conditions over several kilometers.*

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CBL - Communication by light

CBL Communication by light was founded in February 1991 by a team of engineers. The company originates from an engineers´ office in the field of optical communications founded in 1988. Today, CBL stands for the following solutions:

- ✓ Broadband wireless transmission via optical or microwave links mainly for private IP networks;
- ✓ Covering all datarates between 2 Mbps (E1) and 1250 Mbps (Gigabit Ethernet);
- ✓ Distances up to 2 km by own developed optical links and up to 50 km by OEM microwave links;
- ✓ CWDM for fiber optic systems with data rates between 2 .. 2.000 MBit/s and distances up to 150 kilometers;

The history of our experience in FSO is very deep:

1991	First Laser-Link for 10 Mbps Ethernet over 2000 meters
1995	Installation of 38 GHz microwave links (4E1) in private networks
1997	Voice-/data-multiplexer making Laser-Links more efficient
1999	LaserLink 4E1 specially for GSM-applications
2001	AirLaser IP100 with integrated microwave backup
2003	AirLaser IP1000 transmits Gigabit Ethernet with full speed of 1.250 Mbit/s
2003	Optimized LaserLink for STM-1 in GSM networks

In 2002 CBL GmbH and its sister company CBL sro had totaly more than 40 highly qualified employees for R&D, production, sales and support. Revenue of CBL group was over 8 million Euro. CBL is hold by independent private shareholders with a letter capital of 333.000

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