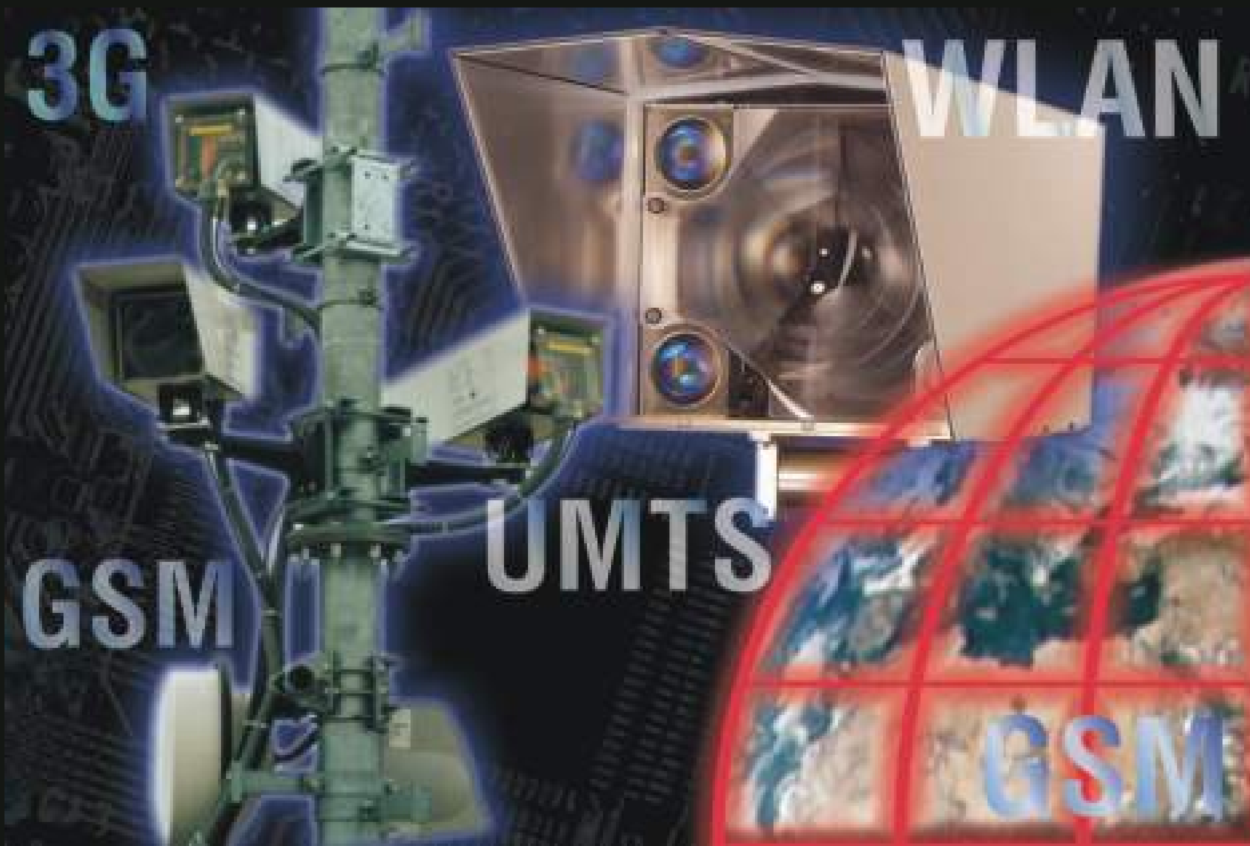
LaserLinks for GSM/UMTS

CBL

Communication by light

Gesellschaft für optische Kommunikationssysteme mbH

I/2003



Free space optics for carrier networks

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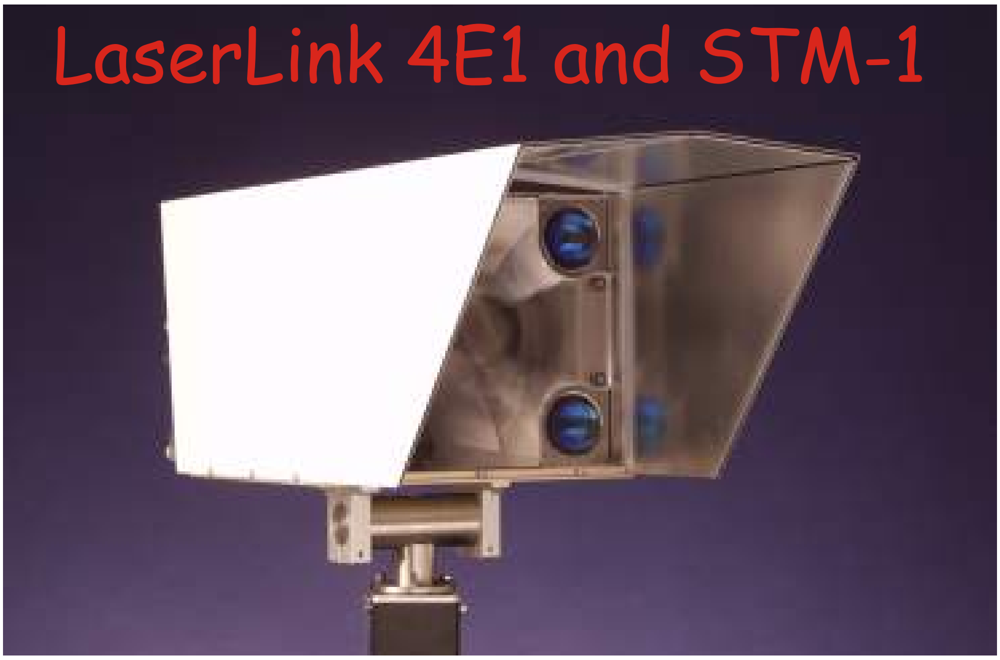
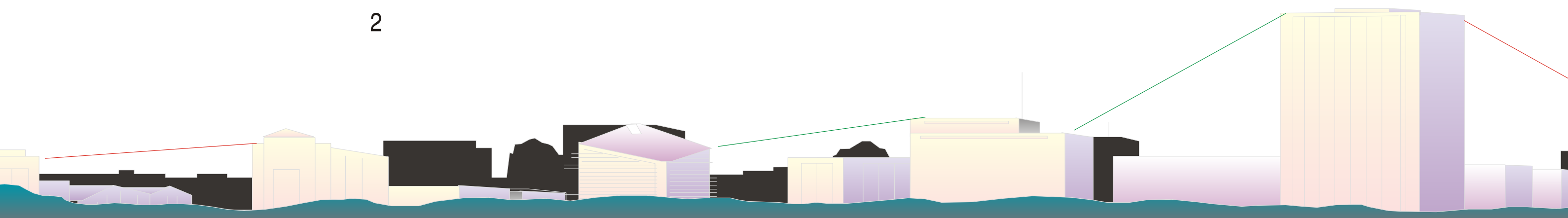




Welcome at CBL!

Dipl.-Ing.
Lutz Jäckels
Marcom Manager

Your GSM/UMTS networks needs 4E1- and/or STM-1 links over less than 1.000 meters! CBL has an alternative to classic mircrowave radios for you: The LaserLink! In this catalogue, we present a proofen solution on the basis of latest technology in free space optics: The LaserLink for PDH and SDH applications. Attached are some physics behind FSO which make the benefits of the technology easier to understand. LaserLinks are not an idea, but real existing products: Since summer 1999 LaserLinks are already under operation in GSM networks. CBL GmbH's sister CBL sro located in Pardubice, Czech Republic, installed hundreds of links . According to the high level of technical requirements from our GSM customers we build up a group of educated people, which specially support implementation of LaserLinks to GSM networks including:

- help with link planning;
- complete installation of equipment at site;
- all kind of maintenance and after sales services.

Since 1991 the CBL Communication by light group has developed, produced and installed far more than 1000 free space optical links (FSO). These links transmit data and voice via the free atmosphere by infrared light. Today, transmission of Fast Ethernet is the major application in the enterprise market. For that reason, CBL developed the AirLaser IP series (further information at www.airlaser.de).

Futhermore CBL has a lot of experience in customer specific development of FSO and fiber optic systems. We are pleased about your feedback for further improvements of our products, technical information and services. Our employees consult you with pleasure concerning your special requirements.

September 2003

Lutz Jäckels

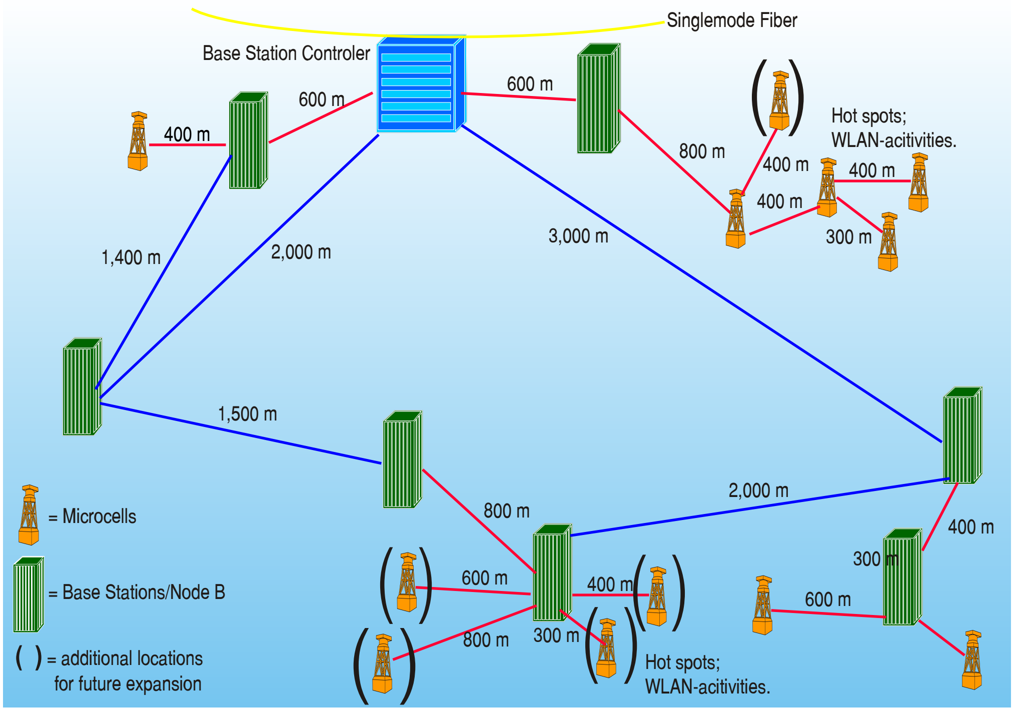
Dipl.-Ing. Lutz Jäckels
Marcom Manager

LaserLink expands your GSM/UMTS network

Modern GSM/UMTS networks need a lot of E1 links between different locations. They are essential for a wide distribution of Base Stations and, if necessary, micro- or pico-cells. Often leased lines can be used, but also a lot of short haul microwave radios are necessary. In the backbone, STM-1 is standard. The best solution for establishing the physical layer is a combination of all available communication media:

- ✓ Copper lines;
- ✓ Fiber optic cables;
- ✓ Microwave links;
- ✓ and LaserLinks.

FSO can also connect Base Stations/Node B because they cover data of various speed via modulated infrared light directly through the atmosphere. Each link comprises of two terminals, which both have an optical transmitter and an optical receiver with the related signal processing inside. These LaserLinks are installed in weatherproofed housings for unlimited outdoor operation in all climes. The LaserLinks are very competitive to all other solutions if distances of less than 800 meters are taken into account.



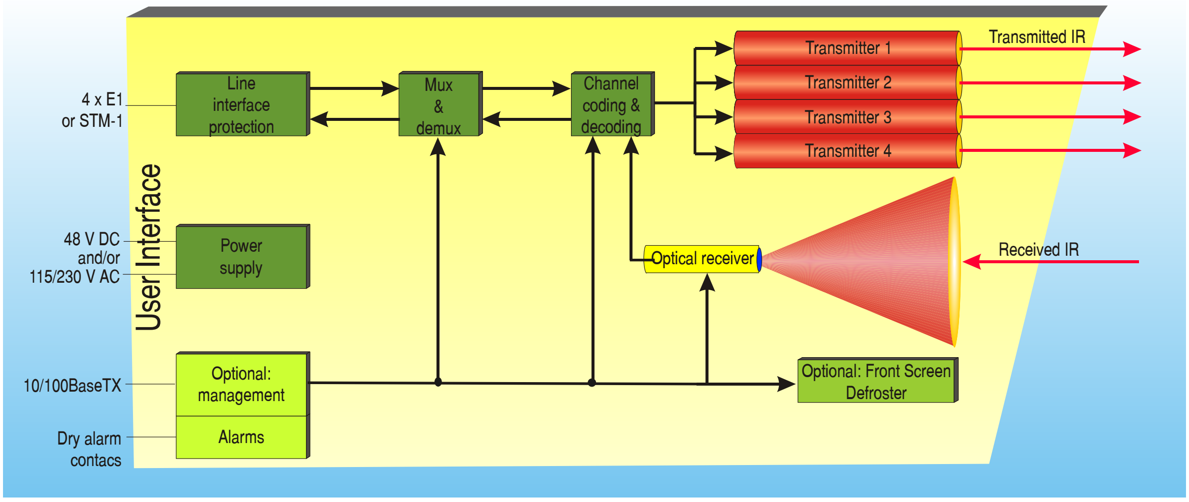
Picture 1: Different locations in a GSM/UMTS have to be connected

Arguments for FSO

The five advantages of communication by infrared light are significant:

- ✓ Simple construction reduces costs per link and operational costs;
- ✓ No frequency coordination required. Very easy link planning and setup;
- ✓ FSO can carry data-rates at STM-1 and beyond very easy;
- ✓ No stringent radio licensing regulations;
- ✓ Environment safe installation and operation.

Gerneration, modulation and detection of infrared light is much easier than handling of GHz-frequencies. Consequences to FSO are: Much less electronics and subsystems and therefore no indoor unit necessary. Simple and robust construction means cost advantage, low power consumption and high reliability. Last but not least: Same unit for both ends of the hop and for all distances keeps logistics and planning very easy.



Picture 2: Simple construction reduces cost per terminal

Benefit #1: LaserLinks cost half the price of a microwave link with the same capacity. The operational costs are much lower.

FSO works with invisible infrared light as carrier medium. The light doesn't interfere with crossing beams so that no frequency coordination is required. Furthermore it is enough for link planning department to check only the direct line of sight. Fresnel zones do not exist for FSO.

Benefit #2: No channel planning and quicker roll out. FSO allows installation in hours and, if necessary, indoor behind windows.

The electromagnetic spectrum in the GHz-range is crowded. FSO works around 850 nm or in the 1550 nm in the THz-band. Here is enough space, also for future Gigabit-channels. This advantage of light as carrier frequency offers much more bandwidth than required today.

Benefit #3: Enough bandwidth for today´s and all new business cases in the future.

Picture 3: Installed LaserLink

FSO is free in the most countries and stringent regulations are absent.

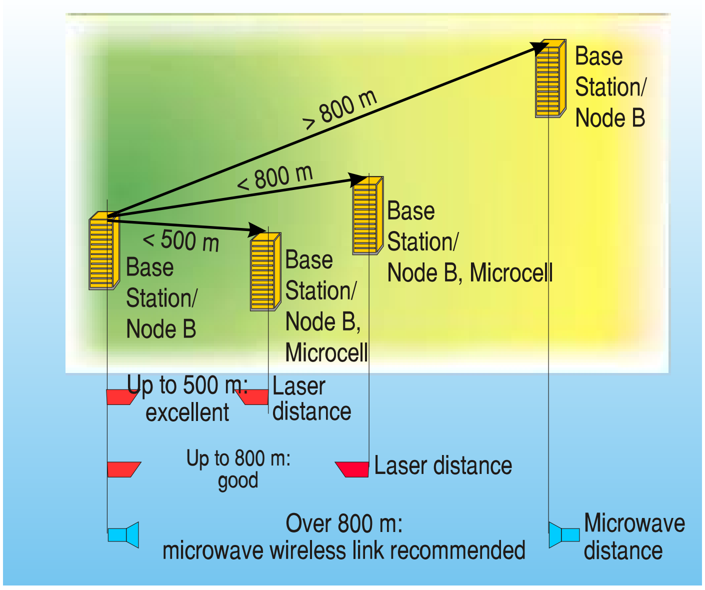
Benefit #4: No license fees.

Some people do not like microwave systems. Infrared is well known from remote control systems. Due to eye safety classification of LaserLinks, no healthy regulations must be obtained.

Benefit #5: Environment safe installation and operation.

Picture 4: Typical microwave installation

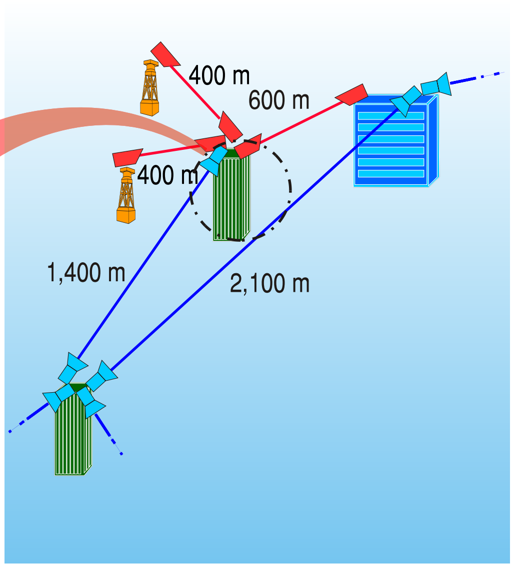
Hop length and availability



Picture 5: Recommended distances for FSO

The physics of light transmission and the influence of weather are explained at the end of this brochure. As a result of fundamental physical laws, five nine availability is not possible over 800 meters in any European climate with any FSO of any manufacturer. Over 500 meters the availability is 99.9 %. Where five nine availability is a must, FSO is deplaced.

Due to its limited hop length and availability, FSO can play a role only in combination with microwave links, fiber optic and copper cables.



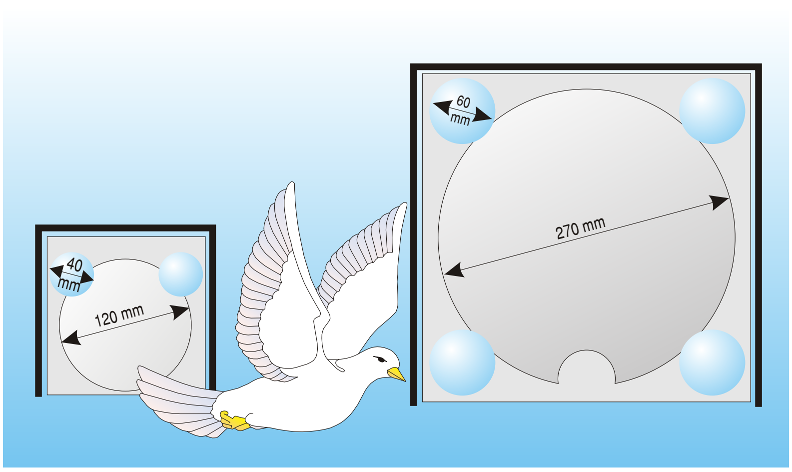
Picture 6: Combination of classic microwave systems and FSO

General about free space optics

In each FSO terminal light emitting diodes (LED) or, if more than 100 Mbps is required, VCSEL-laser diodes are used. Important is an eye-safe Laser class 1M design to avoid restrictions at installation sites. A large beam divergence (> 5 mrad) makes the terminals unsensitive against small movements of mouting poles and buildings. Systems with low divergence (≈ 1 mrad) need expensive internal tracking.

Picture 7:
Front view of LaserLink

After transmission through free space, a big receiver lense focuses the beam onto the optical receiver. Large receiver lense diameters guarantee high system reserve for bad weather. Multibeam technology ensures high power, redundancy and big apertures even in eye safe classification. Furthermore, it is essential for transported PDH/SDH-signals that flying birds can not interrupt the beam.



Picture 8:
Different optics regarding the size of flying birds.

For installation and maintenance an integrated telescope, build-in system-tester together with a receiving level indicator are very useful.

Security of data

Free space optics have excellent protection against tapping. As the signal path is invisible and tightly focused, an optical link can only be monitored by interrupting the signal. This, in turn, would be immediately noticed by the user. Finally, the beam is generally guided at some height above the ground so that unauthorized tapping is nearly impossible.

Hop Length

As mentioned above, weather influences the availability of an optical link. In climate zones with rain, snow and fog like middle Europe approximately 800 meters is a reasonable upper limit. CBL recommends to limit the employment of free space optics for serious PDH/SDH applications to maximum ranges of 2000 meters only in desert climates! The reasons are explained in theory and have nothing to do with engineering.

Picture 9: LaserLink installed in a GSM network in combination with microwave radios

Installation issues and maintenance

The installation of FSO is similar to microwave hops. Only free line of sight between both ends is necessary. The terminals can be installed on standard poles, where microwave radios are mounted, too.

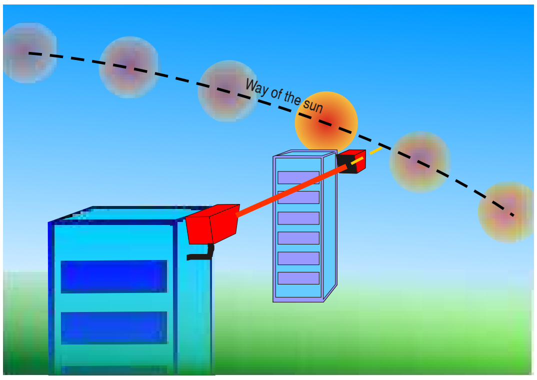
If the divergence of the optical beam is around a half degree and therefore similar to its counterpart, the antenna angle in microwave systems, the allowable motion of the terminal is like that for microwave radios. No special planning is necessary!

Generally, it is possible to install the terminals indoor behind a window. This could be necessary in historic buildings, dense urban areas or whereever the terminals should be installed invisible.

Sunlight does not affect LaserLink systems in normal operation. A combination of narrow field of view, optical filtering to remove out-of-band light and DC offset removal in the receiver ensures that links remain working day and night.

Picture 10: Indoor installation of LaserLink

In some very special installations with direct East/West orientation, roughly 1 per cent of all installations, temporarily blinding of the remote receiver is possible during sun rising or setting behind one end of the link. If the sun is shining the result may be an overload of the optical receiver. During 5 to 10 minutes, the link is not available. Typically a disk of a half degree equivalent to 8 mrad around the sun is able to blind the



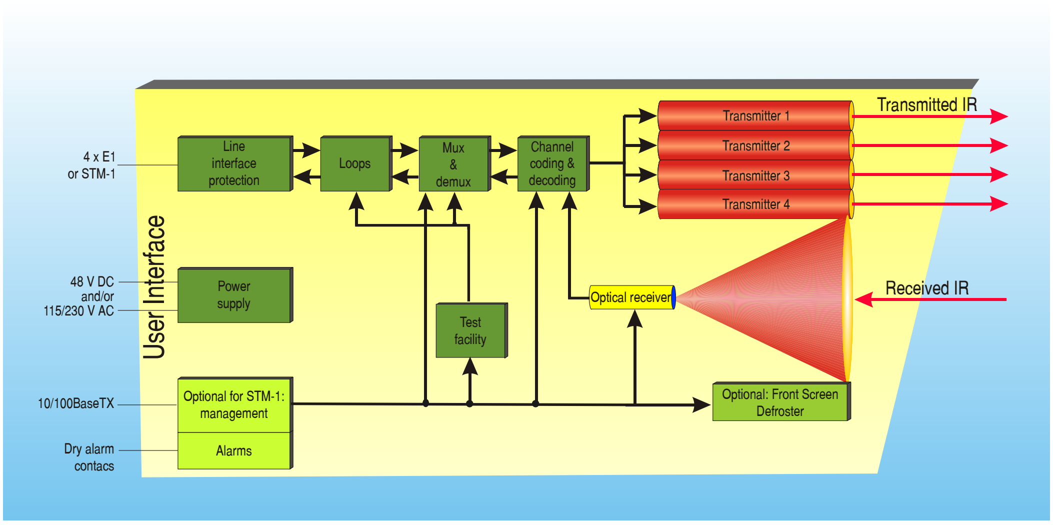
Picture 11: Sun blinds LaserLink temporarily when in the receiver´s field of view

optical receiver. Often this can be avoided if the terminals are not installed on the highest points of a building. No damage occurs and recovery is automatic. This phenomenon affects all types of FSO.

Depending on the pollution in the air, the front windows of the terminals should be cleaned once each two years.

CBLs LaserLinks - a reliable solution

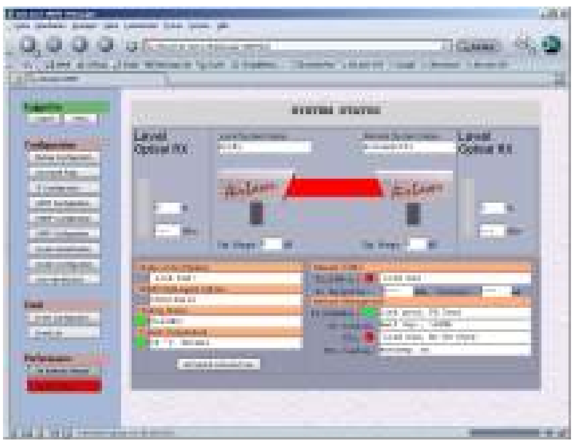
CBL offers one version for 4E1-PDH traffic and one version for STM-1 traffic. Both are suited for all distances between 50 and 2000 meters and both use the same terminal at each end of the link. The block diagram gives an overview of the construction. All LaserLinks is common that four transmitter are switched parallel to enlarge their aperture and power. Due to influence of birds, receiver's lense has 257 mm diameter. The channel codec and the line interface are version-depended.



Picture 12: Block diagram of LaserLink

For the LaserLink STM-1 a SNMP/web-based management for monitoring and configuration with an easy-to-use graphical user interface is available. The web-site *www.airlaser.de* gives access to a life management demo.

CBL's solution provides management access via IP (Ethernet 10/100BT) and allows the permanent monitoring of configuration, fault and perfomance.



Special items are:

✓ Email-alarming;

✓ extensive historical logging capability;

✓ integration into existing SNMP-platforms such as e.g. HP OpenView with an also supplied private MIB, supports RFC1213 and SNMPv1/2.

For the PDH version, only dry alarm contacts are available for external tunneling. CBL recommends to switch these alarm contacts to the base stations to be connected.Then the main functions of the LaserLink 4E1 will be visible to the OMC very quick, easy and inexpensive.

An option is the front screen defroster, useful in northern regions.

CBL provides an universal holder which is suited for poles between 89 mm and 115 mm diameter and for mounting in front of a wall.

The idea behind the LaserLink is creating an universal chassis. Due to an internal modular concept, many customer specific modifications are possible.

Picture 13: Transparent backpanel of the LaserLink 4E1

Main benefits of LaserLink:

- ✓ Only one type per capacity PDH or SDH for full distance range reduces spare parts;
- ✓ Large divergence, therefore no special pole constructions or expensive tracking systems are necessary;
- ✓ Multibeam technology with large transmitter and receiver aperture offers best immunity against interruptions caused by rain, snow and birds;
- ✓ Unique SNMP/Web-based management is available for LaserLink STM-1;
- ✓ Eye safe laser class 1M operation;
- ✓ Low power consumption at 48VDC optional 115/230 VAC with automatic switch over.

LaserLink - technical data

Technical data	LaserLink 4E1	LaserLink STM-1
Capacity	4 x E1 = 4 x 2.048 Mbps	STM-1 = 155 Mbps
Interface	G.703	G.957 S-1.1
Physical connection	Sub-D25, all 120 Ohms	dSC connector to 9/125 µm-fibers
TX (min/max)/ RX (min/max)	-	-15 / - 8 dBm / -30 / -7 dBm
Fiber wavelength	-	1310 nm
Recommended distance	50 .. 2000 meters depending on climate	
Optical performance		
Optical system budget	at 800 m: 29 dB	at 800 m: 26 dB
Maximum attenuation at distance	36 dB/km at 800 m	32,5 dB/km at 800 m
Theoretical distance at 10 dB/km at 30 dB/km	2,100 m 950 m	1,850 m 800 m
Minimum visibility at installed distance	470 m at 800 m	500 m at 800 m
Quality of service		
G.821/826 BER	10 E-8 (unfaded)	10 E-9 (unfaded)
Delay of each terminal	8 µsec	100 nsec
Transmitter		
Multi-beam technology	4 x IR-LED	4 x VCSEL
Wavelength	860 ± 10 nm	850 ± 5 nm
Launched power	4 x 20 mW (eq + 19 dBm)	4 x 5 mW (eq + 13 dBm)
Aperture	4 x 60 mm ∅	
Total transmitting area	113 cm^2	
Divergence	10 mrad	6 mrad
Laser class	Class 1M, eye safe	
Receiver		
Aperture	257 mm diameter	
Total receiving area	520 cm^2	
Field of view	5 mrad	
Type	Si-PIN-TIA	Si-APD-TIA
Sensitivity	+3 .. –45 dBm optical (BER 10E-6)	-6 .. -43 dBm optical (BER 10E-9)
Dynamic range	48 dB	37 dB
Management	-	SNMP and Web-based
Dry alarm contacts	yes	-
Miscellaneous		
Built-in telescope	yes	
Local and remote loop	sep. per E1-channel/all	yes
Bit error rate indicator	yes	
10 LED bar-graph level indicator	yes	
Reducing power steps	16 dB + ATPC	3, 6, 9 dB
Automatic power control	ATPC 6 dB	-
MTBF	more than 100,000 hours	
Movement on holder	azimut 360 deg., elevation ± 25 deg.	
Front screen defroster	optional	
Housing	Aluminum, powder coated	
Power supply	48 VDC and/or 115/230 VAC 50..60 Hz	48 VDC (115/230 VAC optional)
Power consumption (without defroster)	17 VA	27 VA
Dimensions	790 mm x 306 mm x 283 mm (LWH)	
Weight	9,3 kg	10,7 kg
Protection class	IP 64	
Operation temperature	-40..+50 deg. C (-40..+122 deg F)	-25..+50 deg. C (-13..+122 deg. F)
Storage temperature	-40 .. + 80 deg. C (-40 .. 176 deg. F)	
Wind load at 200 km/h	max. 500 N	

Any changings in technical data are no subject to prior notice!

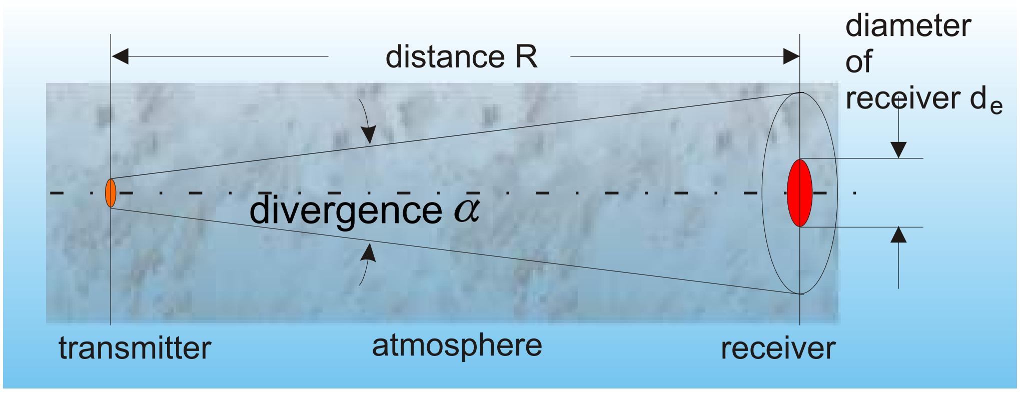
Theoretical background of FSO

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 defraction are the consequences which may interrupt the transmission in excess.

All this effects take place everywhere and every time when light carries data through the atmosphere. Three effects 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

$$a_{geom} = 20 \cdot \log\left(\frac{\alpha \cdot R}{d_e}\right) dB \qquad \text{[eq. 1]}$$

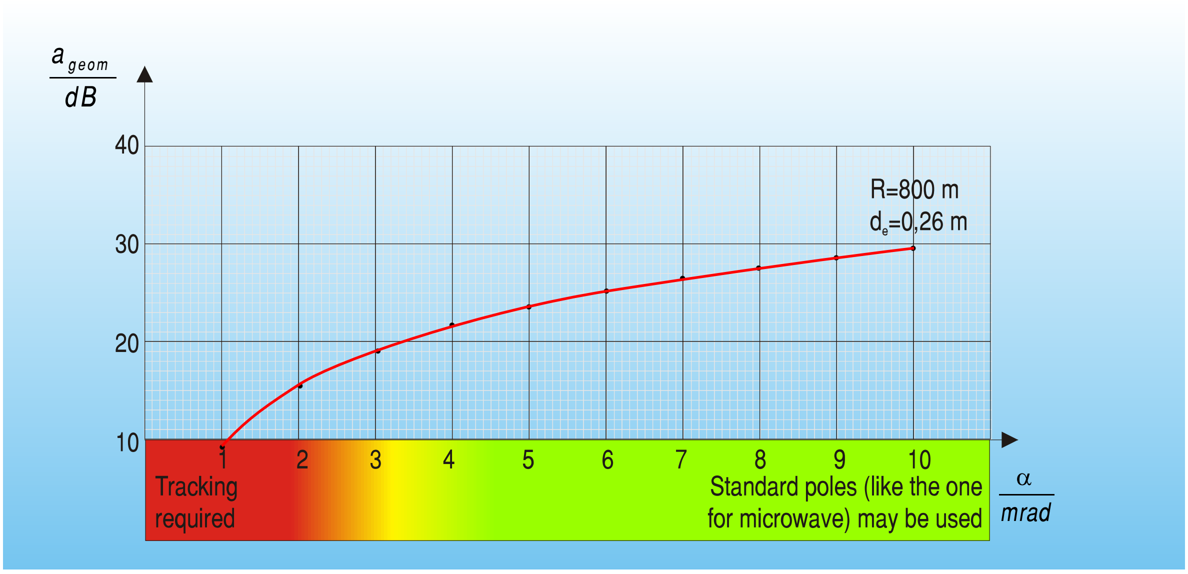
The distance R given in meter, the divergence α of the outgoing light beam in radiant and the diameter d_e of the receiver also in meter.

α 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 movement of building and poles, where terminals are installed on. To use the same poles like for microwave systems, CBL recommends divergences of minimum 5 mrad or internal tracking systems.

Increasing 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.

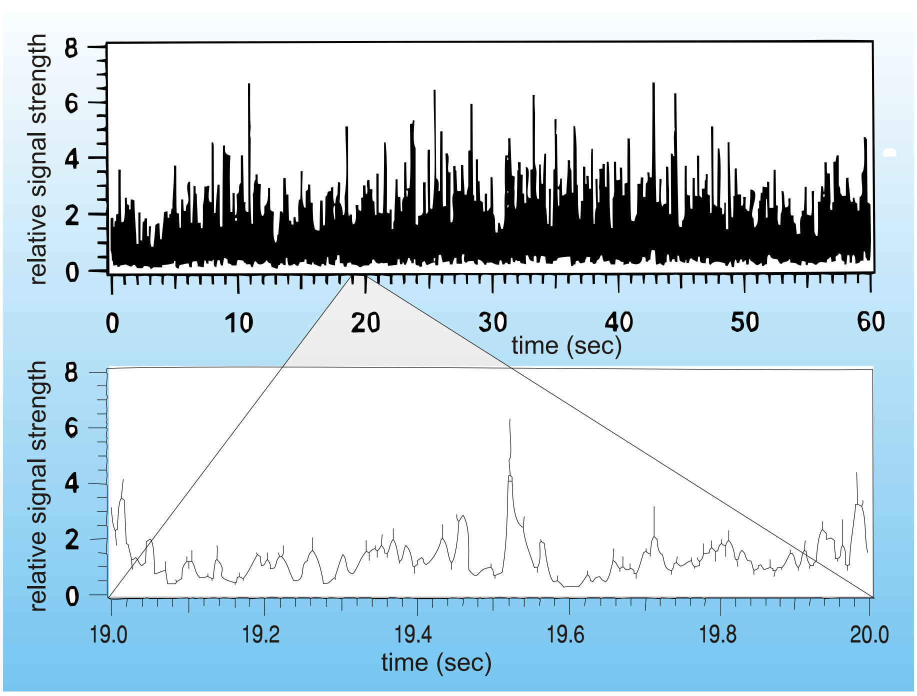


Picture 15: Geometrical attenuation a_{geom} versus divergence α

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. You can see it at star´s light during 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 it takes a lot of attention for the designer that it will not be converted to jitter in later steps of the signal processing unit. One way to beat this scintillation effect is to use large receiver apertures. A collection aperture that is much 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 what also contributes an averaging effect. LaserLinks uses both methodes: large aperture and multibeam technology with four transmitters.



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

Conclusion: *For scintillation, 2 dB per km hop length should be regarded. This is independent of the geometrical attenuation.*

Molecular attenuation and scatter

Air consists of a lot of different gases, water vapour, 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.

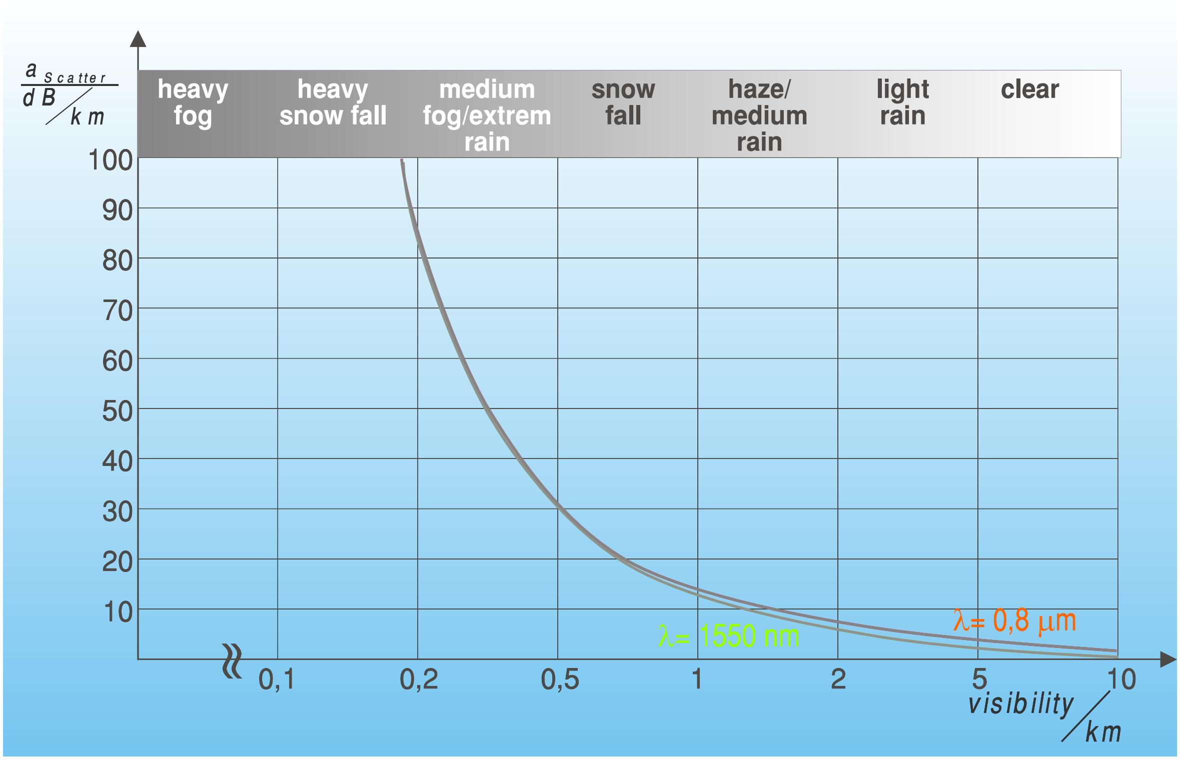
A lot of experiments lead to the following empirically determined equation:

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

The result for the scatter attenuation depends on the visibility S in km and the wavelength λ given in μm. Visibility S is that distance, within 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: *This extreme differences are the reason, why FSO over some kilometers cannot work under all weather conditions.*

Wavelength

FSO can be operated around 850 nm or in the 1550 nm band. Reasons for selecting 1550 nm are: eye safe systems may have 10 dB more power, receiver sensitivity is 3 dB better and faster components are available. Unfortunately, components are more expensive and therefore CBL offers only 850 nm systems.

Transmitter

Two different light sources can be taken into account: Infrared light emitting IR-LED or VCSEL-laser diodes. Both have a MTBF beyond 100.000 hours. The size of the light emitting area of IR-LEDs is 50 to 100 times bigger than of VCSEL-lasers. This means, that different optics for both are needed. VCSEL-lasers offer the advantage that they can be modulated by signals up to the Gbps range. The light of both sources is very divergent, so that perfect adapted lenses or mirror optics are essential to convert the outgoing light into a nearly parallel beam with low divergence.

It is not recommended to increase the transmitted power to more than 10 to 20 milliwatts per transmitter at 850 nm wavelength due to laser class 1M regulations.

Picture 18: VCSEL-laser diode (left), IR-LED (right)

Usually, birds may interrupt the infrared beam. Depending on the transmitted signal, problems can be the result of this short interruptions between 10 and 100 milliseconds. A strategy to avoid bird's influence, is to use as large transmitter and receiver apertures as possible. This leads to large lense diameters with long focus length and to several transmitters which work parallel in a multi-beam configuration.

Receiver

Simple and cheap receivers are operated by PIN-diodes. Up to 10 dB more sensitivity is possible, if APD-diodes convert light into current. Unfortunately, they are more expensive. The most important design rule is: Collection of as many light as possible using a wide aperture. This reduces the geometrical attenuation, the effects from scintillation and also the influence of interruptions by birds. For this purpose the designer selects lenses or mirrors with big diameters. A multibeam configuration is also possible. Note that the total area of the receiver has the same meaning like the antenna gain in microwave systems.

The sensitivity of a PIN receiver with 10 MHz bandwidth is typically -45 dBm. This is enough to ensure bit error rates less than 10^{-8} under normal, unfaded conditions.

Picture 19:
APD (left) and PIN (right) diode

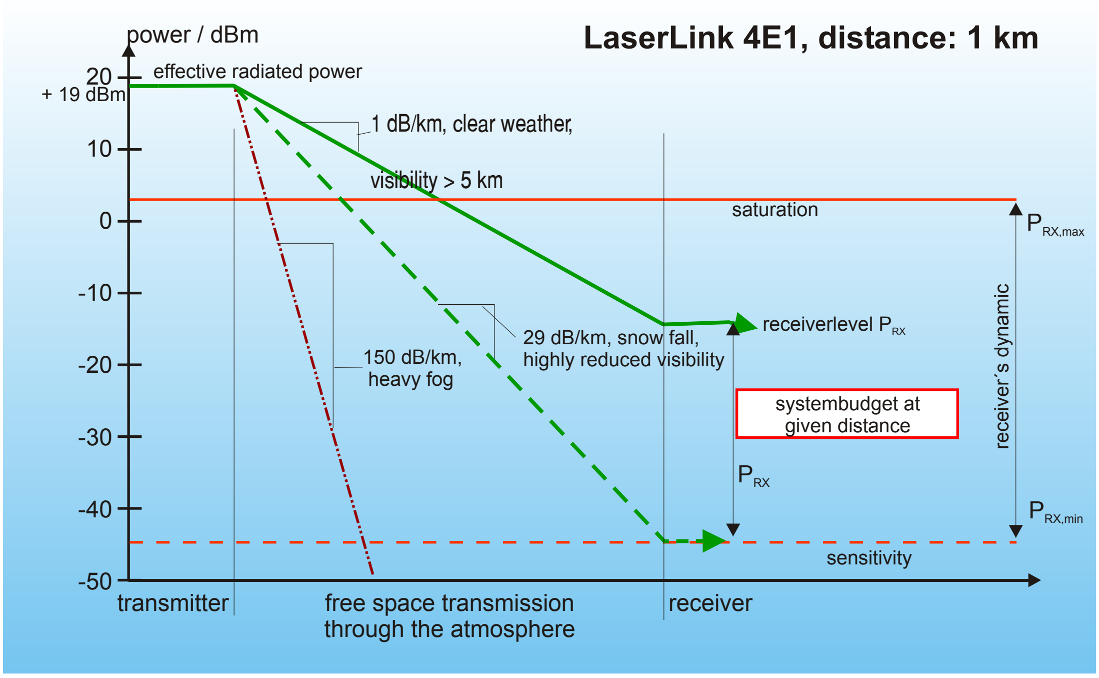
Level diagram

To compare FSO of different verndors, the most important item is their **system budget at a given distance.** All other parameters like transmitted power, divergence, receiver aperture and sensitivity result in the budget.

System	LaserLink 4E1		LaserLink STM-1	
distance	0,5 km	1,0 km	0,5 km	1,0 km
launched transmission power	+19,0 dBm	+19,0 dBm	+13,0 dBm	+13,0 dBm
geometrical attenutation	-25,8 dB	-31,8 dB	-21,3 dB	-27,3 dB
atmospheric attenuation (clear weather)				
scatter: 1 dB/km	-0,5 dB	-1,0 dB	-0,5 dB	-1,0 dB
scintillation: 2 dB/km	-1,0 dB	-2,0 dB	-1,0 dB	-2,0 dB
maximum receiver level	-8,3 dBm	-15,8 dBm	-9,8 dBm	-17,3 dBm
sensitivity	-45,0 dBm	-45,0 dBm	-43,0 dBm	-43,0 dBm
system budget	36,7 dB	29,2 dB	33,2 dB	25,7 dB

Picture 20:
Calculation of system budget vs. distance

The system budget shows, how many attenuation from bad weather is permissible. For example: The 4E1 version running over 1 km works with up to 29.2 dB/km attenuation caused by extreme rain (> 150 mm/h) or medium fog.

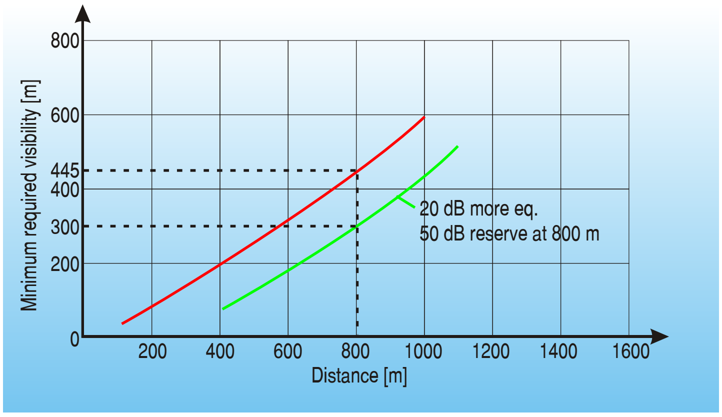


Picture 21:
Weather dependent level diagram

Visibility

The calculation of the required visibility versus hop length delivers the follwing important conclusion:

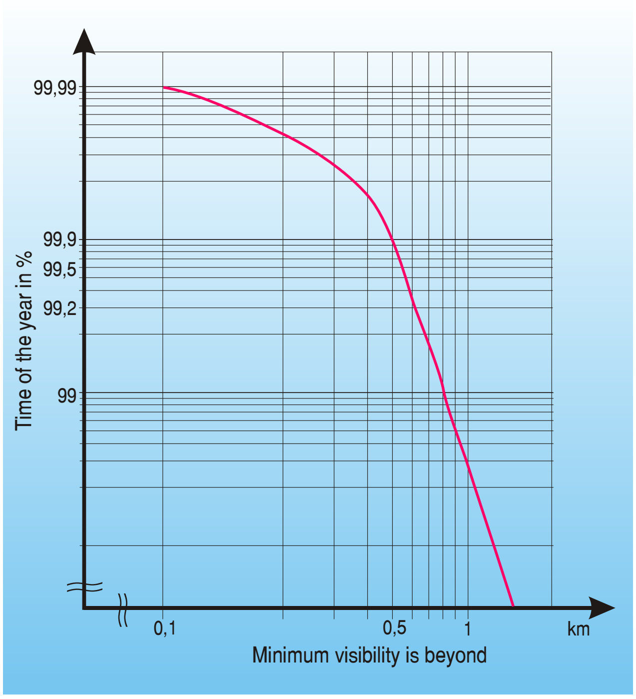
For error free operation of a FSO link, the visibility must be better than 2/3 of the hop length.



Picture 22:
Minimum visibility vs. installed distance of LaserLink 4E1

If it would be possible at reasonable cost to generate 20 dB (!) bigger system budget, the green curve would be the result. Then, for an 800 m hop, only 300 m visibility would be enough instead of 445 m. Small improvements (< 3 dB) are not significant.

To get the availabilty of an FSO hop, it is necessary for a certain location to have the distribution of visibility over the year. Normally for airports and some weather stations the data is available. Unfortunately, they are not always representative for midtowns. For middle Euorpe the following diagram shows the averaged data:



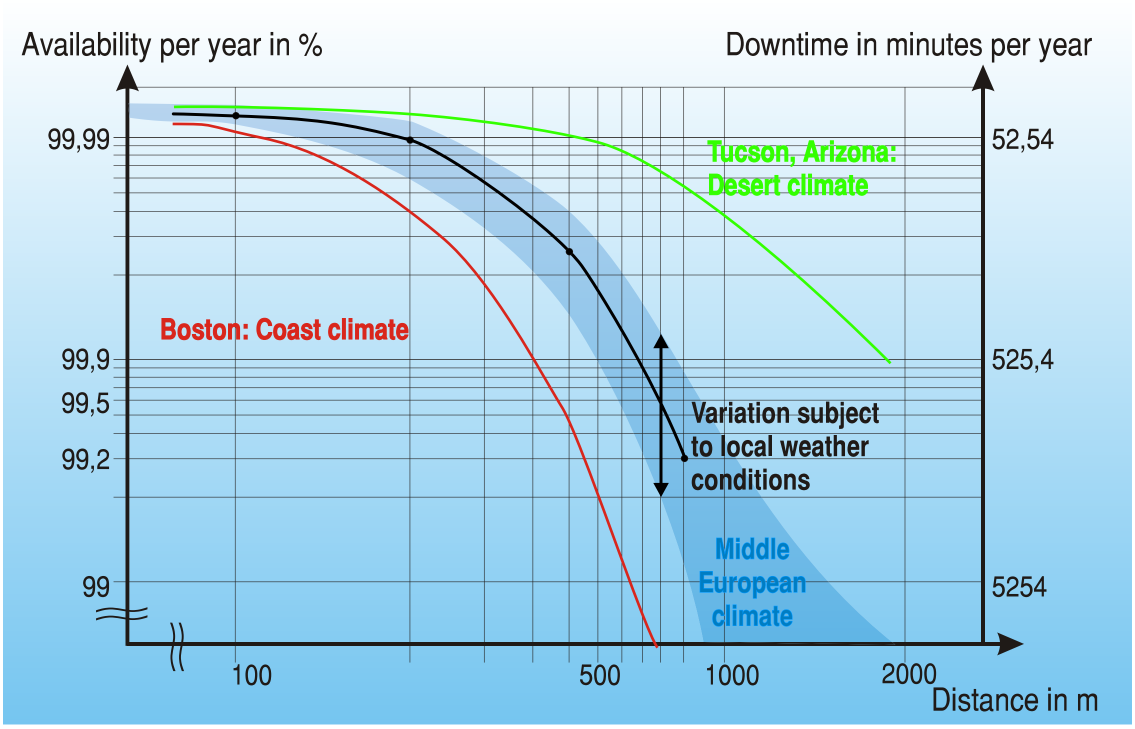
Picture 23: Distribution of visibility for a middle European city

Variations of 20 percent in the visibility do not cause significant variations in the availability during the year. This is a result of the logarithmic relation.

Picture 24: Combination of microwave and FSO

Availability

It is always important to know the availability of a wireless optical link running over a certain distance. Picture 25 shows the availability versus hop length. This is derived from the experience of more than 1000 installed links. Similar to rain zones for microwave radio links, the influence of the very local climate, especially the probability of fog and heavy snow fall has to be obtained.



Picture 25: Availability vs. hop length

There is a big difference in availability between extremly dry desert climates and foggy regions!

Conclusion: *Due to this facts, our recommendation is using FSO for GSM/UMTS applications in regions with rain, snow and fog only for distances less than 800 meters. In dry southern climate, more may be possible. Otherwise the availability will be not satisfying for PDH/SDH applications. This reason is physics behind FSO, not CBL's engineering.*

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Combinations of microwave and FSO systems in operation

Communication by light

Gesellschaft für optische Kommunikationssysteme mbH

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 Euros.

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