

A  
SEMINAR REPORT  
ON  
**Free Space optic**

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**DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGG.**

# PREFACE

Technology has rapidly grown in past two-three decades. An engineer without practical knowledge and skills cannot survive in this technical era. Theoretical knowledge does matter but it is the practical knowledge that is the difference between the best and the better. Organizations also prefer experienced engineers than fresher ones due to practical knowledge and industrial exposure of the former. So it can be said the industrial exposure has to be very much mandatory for engineers nowadays. The practical training is highly conducive for solid foundation for:

- Solid foundation of knowledge and personality.
- Exposure to industrial environment.
- Confidence building.

Enhancement of creativity

# **ACKNOWLEDGEMENT**

I express my sincere thanks to my seminar guide Prof. R.L.Dua (Electronics Department) for guiding me right from the inception till the successful completion of the seminar . I sincerely acknowledge him for extending their valuable guidance , support for literature , critical reviews of seminar and the report and above all the oral support he had provide to me with all stages of this seminar.

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# **INTRODUCTION**

Free space optics (FSO) is an optical communication technology that uses light propagating in free space to transmit data between two points. The technology is useful where the physical connections by the means of fibre optic cable are impractical due to high costs or other considerations.

Free Space Optics (FSO) communications or Optical Wireless, refers to the transmission of modulated visible or infrared (IR) beams through the atmosphere to obtain optical communications.

Free space optical communications is a line-of-sight (LOS) technology that transmits a modulated beam of visible or infrared light through the atmosphere for broadband communications. In a manner similar to fiber optical communications, free space optics uses a light emitting diode (LED) or laser (light amplification by stimulated emission of radiation) point source for data transmission. However, in free space optics, an energy beam is collimated and transmitted through space rather than being guided through an optical cable. These beams of light, operating in the TeraHertz portion of the spectrum, are focused on a receiving lens connected to a high sensitivity receiver through an optical fiber.

Unlike radio and microwave systems, free space optical communications requires no spectrum licensing and interference to and from other systems is not a concern. In addition, the point-to-point laser signal is extremely difficult to intercept, making it ideal for covert communications. Free space optical communications offer data rates comparable to fiber optical communications at a fraction of the deployment cost while extremely narrow laser beam widths provide no limit to the number of free space optical links that may be installed in a given location.

The fundamental limitation of free space optical communications arises from the environment through which it propagates. Although relatively unaffected by rain and snow, free space optical communication systems can be severely affected by fog and atmospheric turbulence.

Free Space Optics are additionally used for communications between spacecraft. The optical links can be implemented using infrared laser light, although low-data-rate communication over short distances is possible using LEDs. Maximum range for terrestrial links is in the order of 2-3 km, but the stability and quality of the link is highly dependent on atmospheric factors such as rain, fog, dust and heat. Amateur radio operators have achieved significantly farther distances (173 miles in at least one occasion) using incoherent sources of light from high-intensity LEDs. However, the low-grade equipment used limited bandwidths to about 4kHz. In outer space, the communication range of free-space optical communication is currently in the order of several thousand kilometers, but has the potential to bridge interplanetary distances of millions of kilometers, using optical telescopes as beam expanders.

FREE-SPACE optical communication has attracted considerable attention recently for a variety of applications. Because of the complexity associated with phase or Frequency modulation, current free-space optical communication systems typically use intensity modulation with direct detection (IM/DD). Atmospheric turbulence can degrade the performance of free-space optical links, particularly over ranges of the order of 1 km or longer. Inhomogeneities in the temperature and pressure of the atmosphere lead to variations of the refractive index along the transmission path. These index inhomogeneities can deteriorate the quality of the received image and can cause fluctuations in both the intensity and the phase of the received signal. These fluctuations can lead to an increase in the link error probability, limiting the performance of communication systems. Aerosol scattering effects caused by rain, snow and fog can also degrade the performance of free-space optical communication systems but are not treated in this paper.

Atmospheric turbulence has been studied extensively and various theoretical models have been proposed to describe turbulence-induced image degradation and intensity fluctuations (i.e., signal fading). Two useful parameters describing turbulence-induced fading are, the correlation length of intensity fluctuations and the correlation time of intensity fluctuations. When the receiver aperture can be made larger than the correlation length, then turbulence-induced fading can be reduced substantially by aperture averaging. Because it is not always possible to satisfy the condition, in this paper, we propose alternative techniques for mitigating fading in the regime where. At the bit rates of interest in most free-space optical systems, the receiver observation interval during each bit interval is smaller than the turbulence correlation time.

Throughout this paper, we will assume that and The techniques we consider are based on the statistical properties of turbulence-induced signal intensity fading, as functions of both temporal and spatial coordinates. Our approaches can be divided into two categories: temporal-domain techniques and spatial-domain techniques.

In the temporal-domain techniques, one employs a single receiver. If the receiver has knowledge of the marginal fading distribution, but knows neither the temporal fading correlation nor the instantaneous fading state, a maximum-likelihood (ML) symbol-by-symbol detection technique can be used. If the receiver further knows the joint temporal fading distribution, but not the instantaneous fading state, the receiver can use a ML sequence detection (MLSD) technique to mitigate turbulence-induced fading.

In the spatial-domain techniques, one must employ at least two receivers to collect the signal light at different positions or from different spatial angles. To maximize the diversity reception gain, the multiple receivers should be placed as far apart as possible, so that the turbulence-induced fading is uncorrelated at the various receivers. In practice, however, it may not always be possible to place the receivers sufficiently far apart. Hence, in this paper, making use of the spatial correlation of turbulence-induced fading, we derive the optimal ML detection scheme for correlated spatial diversity reception.

The major drawback, however at present time is that the glass used in fiber optics is very lossy, amounting to a decibel per meter at the very best. In actuality, with present glasses, the losses would amount to thousands of decibels per mile, which makes the material clearly unsuitable for long distance communication.

The present work, then going on principally in the United States, in Britain, and in Japan, aims at the development of very pure glass fibers. If pure enough fibers are successfully development, dielectric waveguides might eventually be used between switching exchanges a few miles apart within cities and towns.

By 1973, if all goes well, at least one satellite will be put aloft carrying laser communication experiments, put up by NASA. It will have taken a full decade to bring this about. In one way or another, many companies and have had a hand in giving impetus to these experiments. But even yet, there has been some expression of fear by people in the optics community that if these experiments should not succeed, or should fail in some significant way, optical communications could be held back for an indefinitely longer period.

# HISTORY

Optical Communication, in various forms, have been used for thousands of years. The Ancient Greeks polished their shields to send signals during battle. In the modern era, semaphores and wireless solar telegraphs called Heliographs were developed, using coded signals to communicate with their recipients.

In 1880 [Alexander Graham Bell](#) and his then-assistant [Charles Sumner Tainter](#) created the [photophone](#), in Washington, D.C. Bell considered it his most important invention. The device allowed for the transmission of sound on a beam of light. On June 3, 1880, [Alexander Graham Bell](#) conducted the world's first wireless [telephone](#) transmission between two building rooftops. Its first practical use came in military communication systems many decades later.

The invention of [lasers](#) in the 1960s revolutionized Free Space Optics. Military organizations were particularly interested and boosted their development. However the technology lost market momentum when the installation of [optical fiber](#) networks for civilian uses was at its peak.

In 1966 [Charles K. Kao](#) and [George Hockham](#) proposed optical fibers at STC Laboratories (STL), [Harlow](#), when they showed that the losses of 1000 db/km in existing glass (compared to 5-10 db/km in coaxial cable) was due to contaminants, which could potentially be removed.



Optical fiber was successfully developed in 1970 by [Corning Glass Works](#), with attenuation low enough for communication purposes (about 20dB/km), and at the same time GaAs [semiconductor lasers](#) were developed that were compact and therefore suitable for transmitting light through fiber optic cables for long distances.

After a period of research starting from 1975, the first commercial fiber-optic communications system was developed, which operated at a wavelength around 0.8  $\mu\text{m}$  and used GaAs semiconductor lasers. This first-generation system operated at a bit rate of 45 Mbps with repeater spacing of up to 10 km. Soon on 22 April, 1977, General Telephone and Electronics sent the first live telephone traffic through fiber optics at a 6 Mbps throughput in Long Beach, California.

The second generation of fiber-optic communication was developed for commercial use in the early 1980s, operated at 1.3  $\mu\text{m}$ , and used InGaAsP semiconductor lasers. Although these systems were initially limited by dispersion, in 1981 the [single-mode fiber](#) was revealed to greatly improve system performance. By 1987, these systems were operating at bit rates of up to 1.7 Gb/s with repeater spacing up to 50 km.

The first [transatlantic telephone cable](#) to use optical fiber was [TAT-8](#), based on Desurvire optimized laser amplification technology. It went into operation in 1988.

Third-generation fiber-optic systems operated at 1.55  $\mu\text{m}$  and had losses of about 0.2 dB/km. They achieved this despite earlier difficulties with [pulse-spreading](#) at that wavelength using conventional InGaAsP semiconductor lasers. Scientists overcame this difficulty by using [dispersion-shifted fibers](#) designed to have

minimal dispersion at 1.55  $\mu\text{m}$  or by limiting the laser spectrum to a single [longitudinal mode](#). These developments eventually allowed third-generation systems to operate commercially at 2.5 Gbit/s with repeater spacing in excess of 100 km.

The fourth generation of fiber-optic communication systems used [optical amplification](#) to reduce the need for repeaters and [wavelength-division multiplexing](#) to increase [data capacity](#). These two improvements caused a revolution that resulted in the doubling of system capacity every 6 months starting in 1992 until a bit rate of 10 [Tb/s](#) was reached by 2001. Recently, bit-rates of up to 14 Tbit/s have been reached over a single 160 km line using optical amplifiers.

The focus of development for the fifth generation of fiber-optic communications is on extending the wavelength range over which a WDM system can operate. The conventional wavelength window, known as the C band, covers the wavelength range 1.53-1.57  $\mu\text{m}$ , and the new *dry fiber* has a low-loss window promising an extension of that range to 1.30-1.65  $\mu\text{m}$ . Other developments include the concept of "[optical solitons](#)," pulses that preserve their shape by counteracting the effects of dispersion with the [nonlinear effects](#) of the fiber by using pulses of a specific shape.

In the late 1990s through 2000, industry promoters, and research companies such as KMI and RHK predicted vast increases in demand for communications bandwidth due to increased use of the [Internet](#), and commercialization of various bandwidth-intensive consumer services, such as [video on demand](#). [Internet protocol](#) data traffic was increasing exponentially, at a faster rate than integrated circuit complexity had increased under [Moore's Law](#).

# THEORY

Free Space Optics (FSO) systems are generally employed for '[last mile](#)' communications and can function over distances of several kilometers as long as there is a clear [line of sight](#) between the source and the destination, and the optical receiver can reliably decode the transmitted information.

There are many forms of non-technological optical communication, including [body language](#) and [sign language](#). Techniques such as [semaphore lines](#), [ship flags](#), [smoke signals](#), and [beacon fires](#) were the earliest form of technological optical communication.

The [heliograph](#) uses a [mirror](#) to [reflect](#) sunlight to a distant observer. By moving the mirror the distant observer sees flashes of light that can be used to send a prearranged signaling code. [Navy ships](#) often use a [signal lamp](#) to signal in [Morse code](#) in a similar way. [Distress flares](#) are used by mariners in emergencies, while [lighthouses](#) and [navigation lights](#) are used to communicate navigation hazards.

[Aircraft](#) use the [landing lights](#) at [airports](#) to land safely, especially at night. Aircraft landing on an [aircraft carrier](#) use a similar system to land correctly on the carrier deck. The light systems communicate the correct position of the aircraft relative to the best landing [glideslope](#). Also, many control towers still have an [Aldis lamp](#) to communicate with planes whose radio failed. [Optical fiber](#) is the most common medium for modern digital optical communication. [Free-space optical communication](#) is also used today in a variety of applications.

# OPTICAL COMMUNICATION



**Optical communication** is any form of [telecommunication](#) that uses [light](#) as the [transmission medium](#).

An optical [communication system](#) consists of a *transmitter*, which encodes a *message* into an optical *signal*, a *channel*, which carries the signal to its destination, and a *receiver*, which reproduces the message from the received optical signal.

# FREE SPACE OPTICAL

## COMMUNICATION



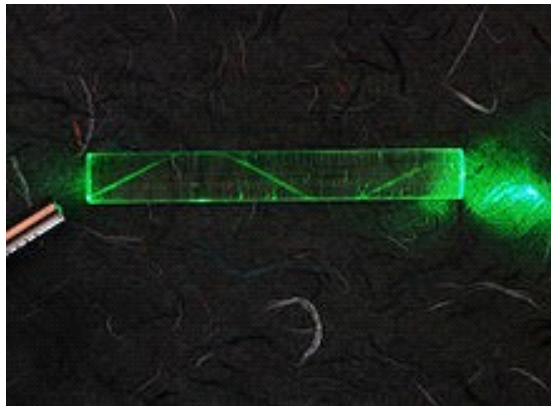
An 8-beam free space optics laser link, rated for 1 Gbit/s at a distance of approximately 2km. The receptor is the large disc in the middle, the transmitters the smaller ones. To the top and right side a monocular for assisting the alignment of the two heads.

In telecommunication, **Free Space Optics** (FSO) is an optical communication technology that uses light propagating in free space to transmit data between two points. The technology is useful where the physical connections by the means of Fibre Optic Cable are impractical due to high costs or other considerations.

# OPTICAL

# FIBER

## COMMUNICATION



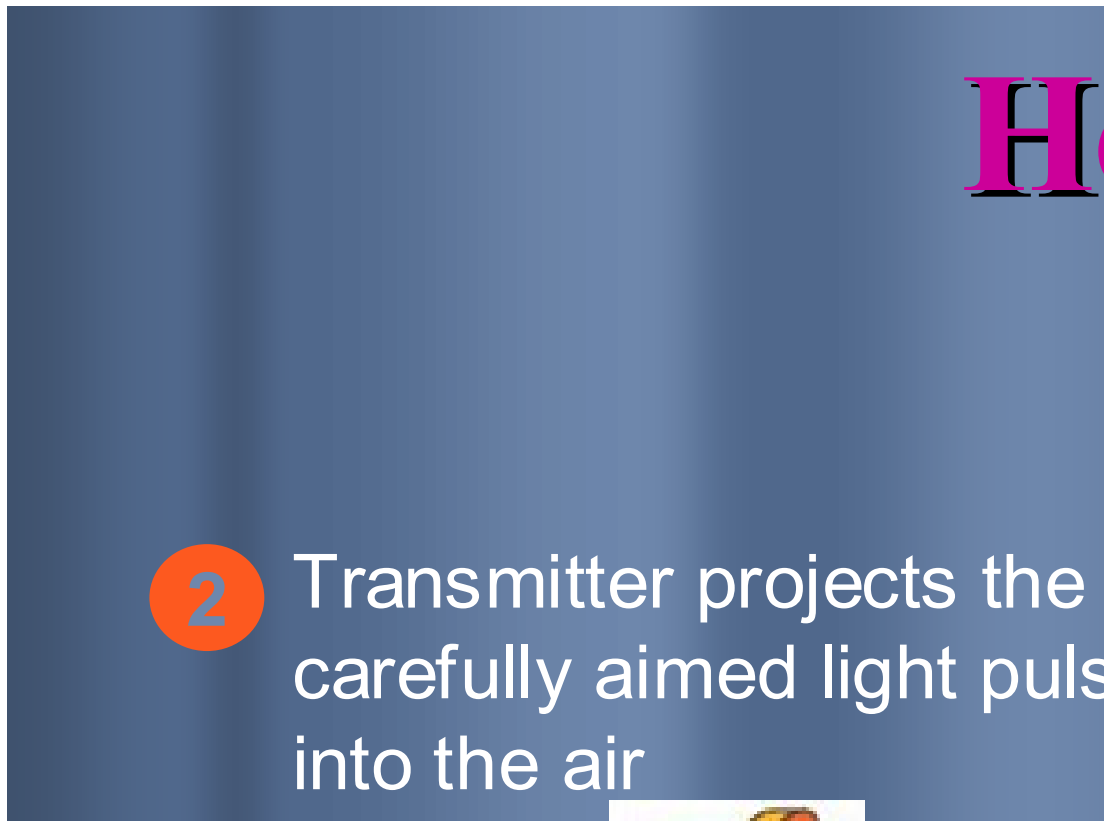
**Optical fiber** is the most common type of channel for optical communications, however, other types of optical [waveguides](#) are used [within computers](#) or communications gear, and have even formed the channel of very short distance (e.g. chip-to-chip, intra-chip) links in laboratory trials. The transmitters in optical fiber links are generally [light-emitting diodes](#) (LEDs) or [laser diodes](#). [Infrared](#) light, rather than [visible light](#) is used more commonly, because optical fibers transmit infrared wavelengths with less [attenuation](#) and [dispersion](#). The signal encoding is typically simple [intensity modulation](#), although historically optical phase and frequency modulation have been demonstrated in the lab. The need for periodic [signal regeneration](#) was largely superseded by the introduction of the [erbium-doped fiber amplifier](#), which extended link distances at significantly lower cost.

In fiber-optic communications, information is transmitted by sending light through optical fibers.

**Fiber-optic communication** is a method of transmitting information from one place to another by sending pulses of [light](#) through an [optical fiber](#). The light forms an [electromagnetic carrier wave](#) that is [modulated](#) to carry information. First developed in the 1970s, fiber-optic [communication systems](#) have revolutionized the [telecommunications](#) industry and have played a major role in the advent of the [Information Age](#). Because of its [advantages over electrical transmission](#), optical fibers have largely replaced copper wire communications in [core networks](#) in the [developed world](#).

The process of communicating using fiber-optics involves the following basic steps: Creating the optical signal involving the use of a transmitter, relaying the signal along the fiber, ensuring that the signal does not become too distorted or weak, receiving the optical signal, and converting it into an electrical signal.

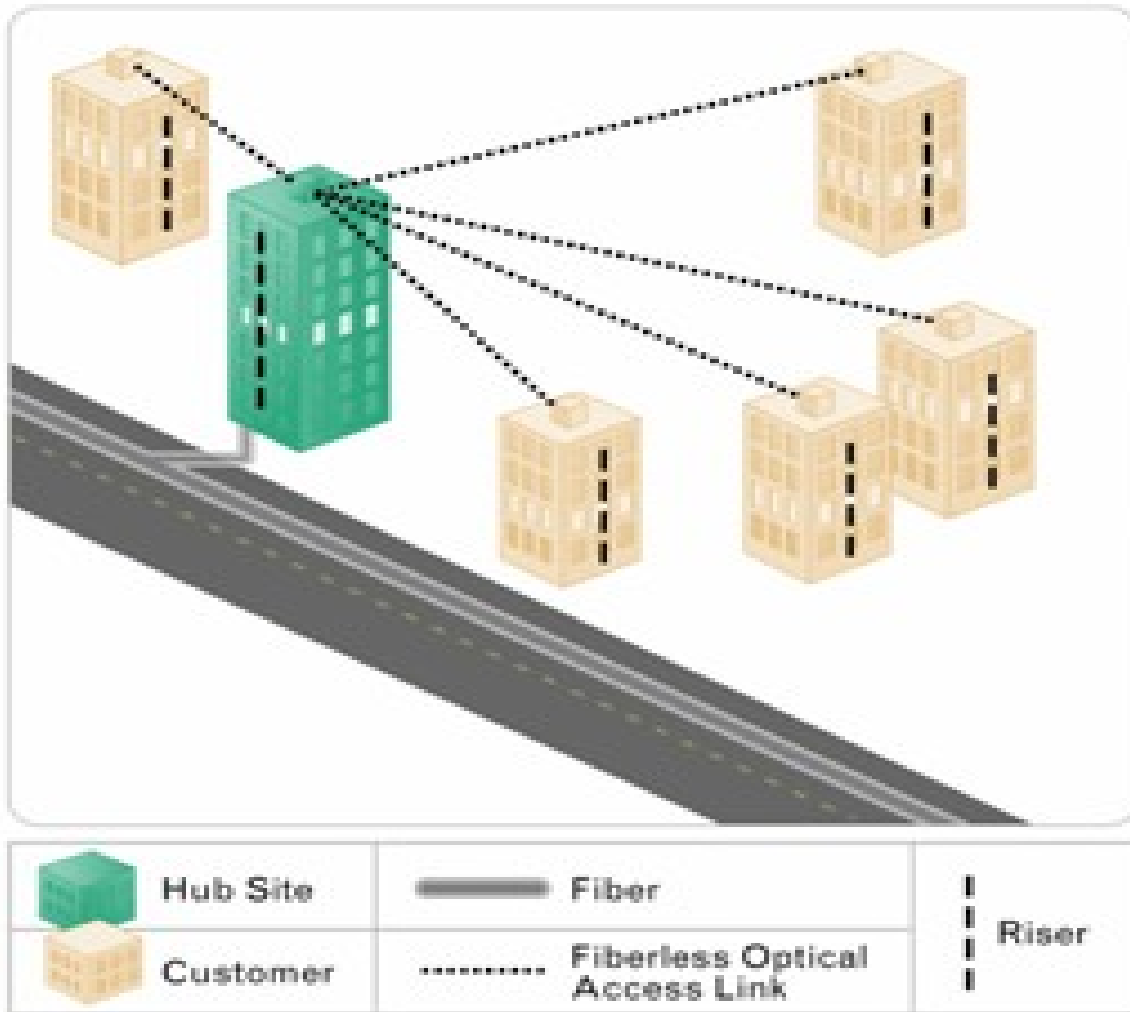
# How Fso WORKS ?????



- 1) Network traffic converted into pulses of visible light representing 1's and 0's.
- 2) Transmitter projects the carefully aimed light pulses into the air.
- 3) A receiver at the other end of the link collects the light using lenses and/or mirrors.
- 4) Received signal converted back into fiber or copper and connected to the network.



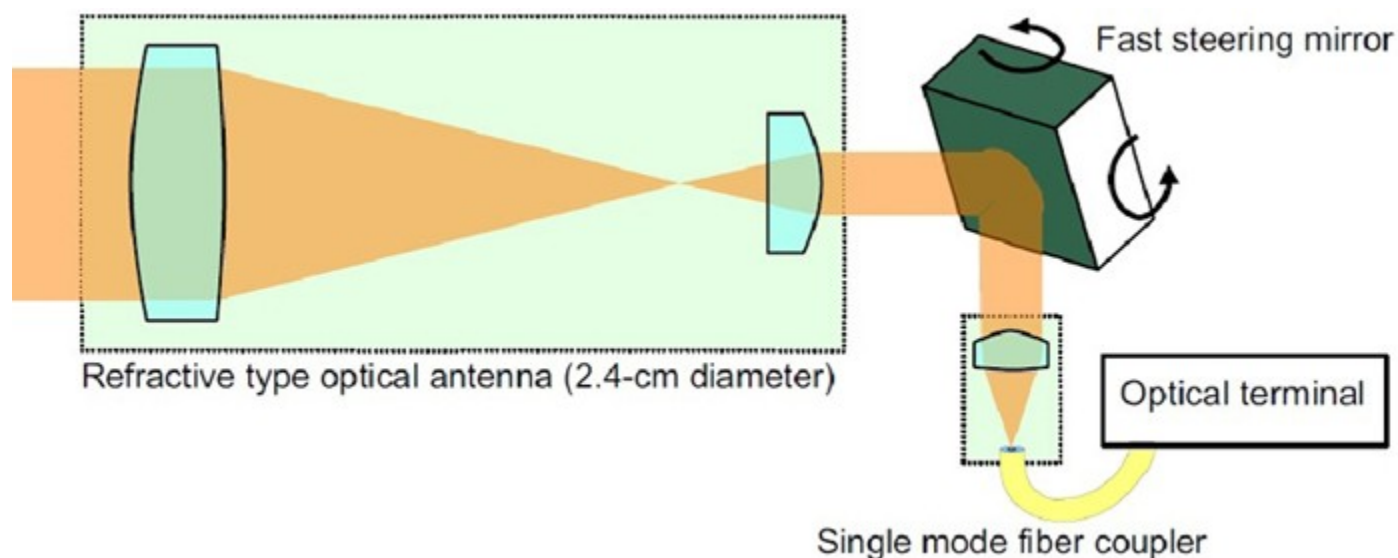
# BENEFITS OF FSO



Free-space optical (FSO) communications can provide flexible, easy-to-install, and license-free line-of-sight wireless-communications links. The high speed and large bandwidth offered by light-wave communication technology make them very attractive as means to meet future demand for broadband Internet access and high-definition television broadcasting services. However, the bit rate of existing FSO links using near-IR lasers in the 780–850nm range is still limited to 1–2.5Gb/s. This is due to both the upper limit to laser power usually adopted to maintain eye-safe light levels and the lack of existing high-speed optical devices required to build multi-gigabit optical terminals.

Longer-wavelength spectral regimes, such as the 1.5 $\mu\text{m}$  band, have maximum permissible exposures that are less critical than that for the 780–850nm range.

They are also attractive because of the wide variety of existing optical devices suitable for multi-gigabit operation. Particularly, erbium-doped fiber amplifiers (EDFAs), which can be engineered for operation at longer wavelengths, are among the most important elements in high-power transmitters and sensitive receivers. To use EDFAs as high-speed optical devices, we must efficiently couple a stable free-space optical beam to a single-mode fiber (SMF)—characterized by a mode-field diameter of approximately 10 $\mu\text{m}$ —because almost all high-speed fiber-optic components are connected by SMFs.



**Figure 1.** Operational concept of our new free-space optical terminal.

In space communications, FSO links are considered the ultimate media to establish high bit-rate data links between satellites. They use diffraction-limited laser beams with large-aperture optics (telescopes) and require accurate pointing and tracking technology. Using these space laser-communication technologies and terrestrial fiber-optic components, we designed a new, compact FSO terminal that provides seamless connectivity with terrestrial fiber-optic networks<sup>1</sup> (see Figure 1). It can be used for link distances of up to 1km.

A refractive telescope with an effective aperture of 2.4cm is used as an optical antenna to collect the incoming laser beam and convert it into a thin, collimated

beam with an internal diameter of 2mm. A fast-steering mirror (FSM) is placed at the telescope's exit pupil to stabilize the angle-of-arrival (AOA) fluctuations of the free-space laser beam. (The latter are caused by vibrations and/or thermal deformations of the terminal support structures and by atmospheric turbulence in the propagation path.)

The stabilized beam is focused into the SMF at the fiber coupler. A tracking sensor using a silicon-quadrant photo detector is integrated into the fiber coupler to detect AOA fluctuations and alignment errors. Based on the horizontal and vertical error signals, an analog proportional-integral-differential servo controller with a bandwidth of  $>5\text{kHz}$  drives the FSM. After SMF coupling, an optical circulator is used to separate incoming and transmitting optical signals. A near-IR beacon is used for bidirectional tracking. We selected wavelengths of 972 and 982nm, both within the EDFA's pump-laser band, for operational tests. The transmitting signal and beacon laser light are multiplexed by a wave-division-multiplexing (WDM) coupler and then transmitted to the opposite terminal using the same optical path as the signal light, i.e., through the fiber coupler, the FSM, and the optical antenna. The overall optical-signal attenuation from the optical aperture to the SMF connector is approximately 2.0dB. The terminal size is  $12\times 12\times 20\text{cm}^3$ , and its total weight is less than 1kg (see Figure 2 for an internal view). The electrical power required for terminal operation including FSM servo and beacon-laser driver is less than 1W.

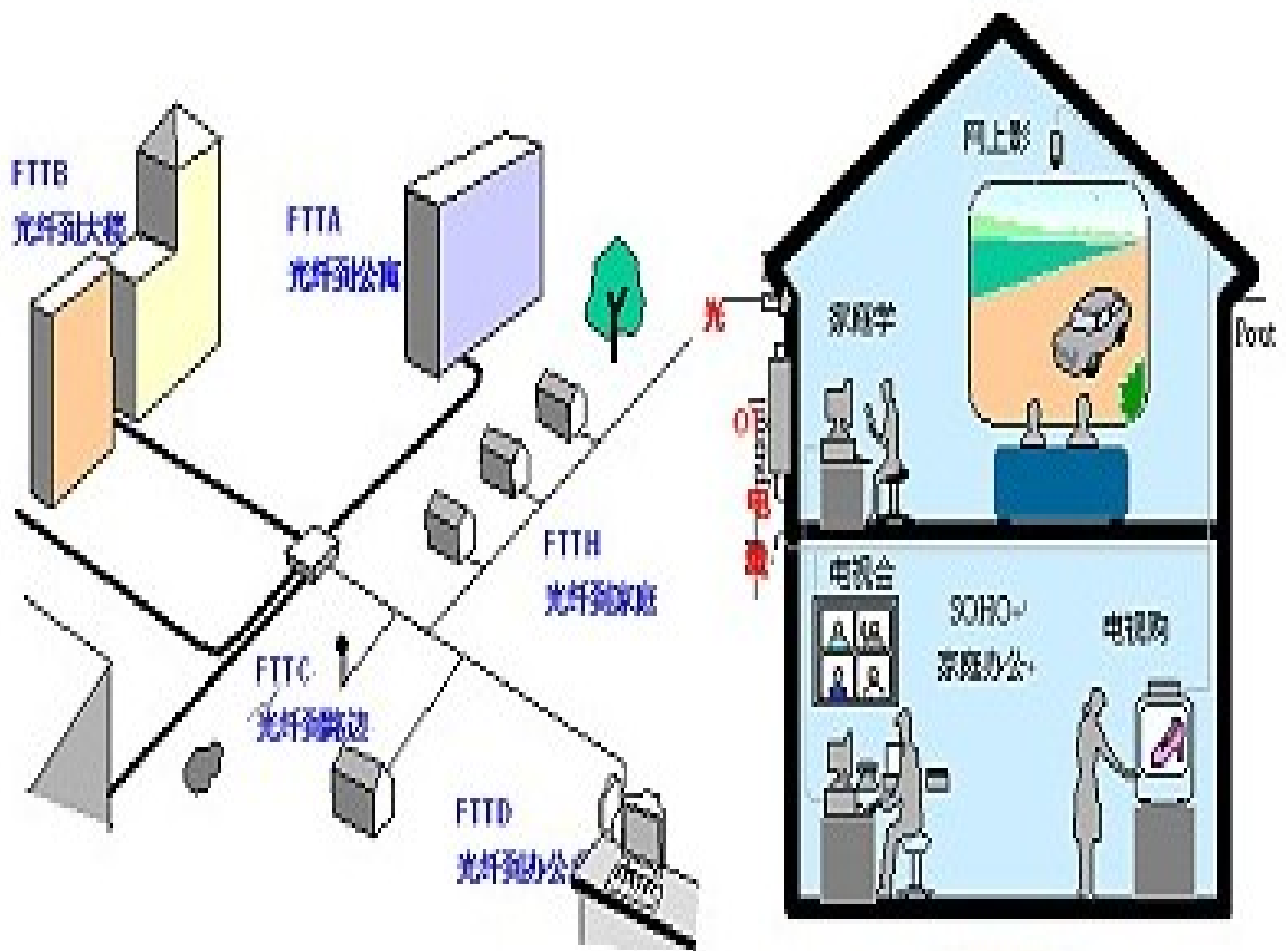
# COMPARISON WITH FSO

	<u>FSO</u>
<b>Distance Range</b>	Up to 60

# OPTICAL

# ACCESS

# COMMUNICATION

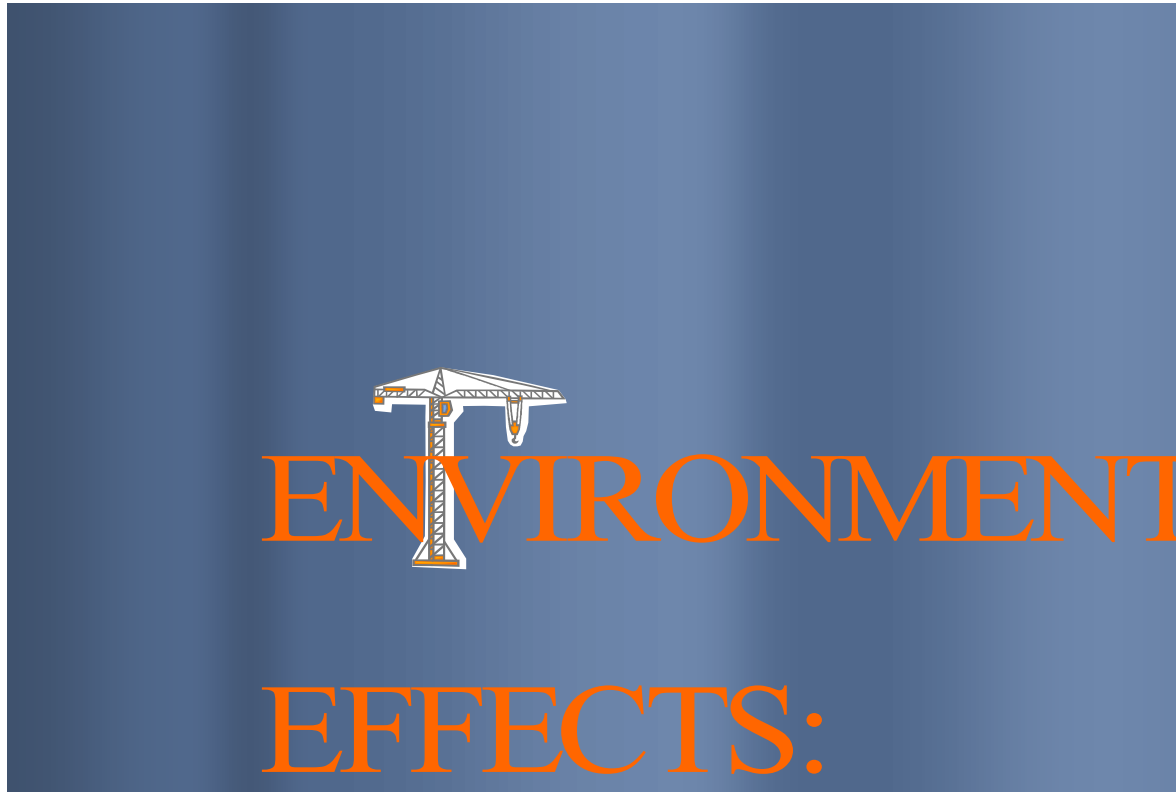


**There are four types of communication through Optical Fiber**

1. Free space optical communication
2. FTTH: Fiber to the home
3. Optical transceiver module

## 4. Access Network Planning

# CHALLENGES



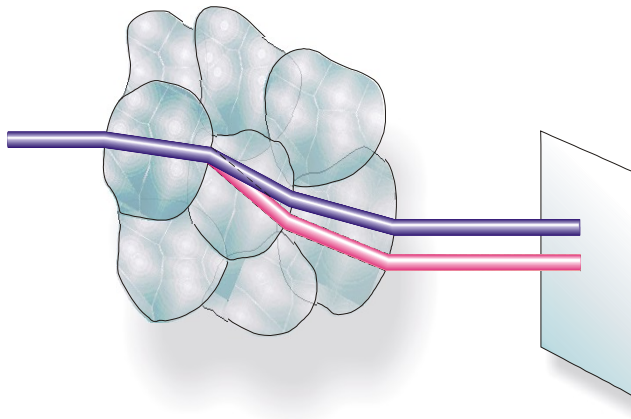
## Atmospheric Attenuation-FOG

- Absorption or scattering of optical signals due to airborne particles
- Primarily FOG but can be rain, snow, smoke, dust, etc.
- Can result in a complete outage
- FSO wavelengths and fog droplets are close to equal in size (Mie Scattering)
- Typical FSO systems work 2-3X further than the human eye can see
- High availability deployments require short links that can operate in the fog

## Low Clouds, Rain, Snow and Dust

- Low Clouds
  - Very similar to fog
  - May accompany rain and snow
- Rain
  - Drop sizes larger than fog and wavelength of light
  - Extremely heavy rain (can't see through it) can take a link down
  - Water sheeting on windows
- Heavy Snow
  - May cause ice build-up on windows
  - Whiteout conditions
- Sand Storms
  - Likely only in desert areas; rare in the urban core

## Scintillation





- Beam spreading and wandering due to propagation through air pockets of varying temperature, density, and index of refraction.
- Almost mutually exclusive with fog attenuation.
- Results in increased error rate but not complete outage.

## **USAGE AND TECHNOLOGIES**

Free Space Optics are additionally used for communications between [spacecraft](#). The optical links can be implemented using [infrared laser](#) light, although low-data-rate communication over short distances is possible using [LEDs](#). Maximum range for terrestrial links is in the order of 2-3 km, but the stability and quality of the link is highly dependent on atmospheric factors such as rain, fog, dust and heat. Amateur radio operators have achieved significantly farther distances (173 miles in at least one occasion) using incoherent sources of light from high-intensity LEDs. However, the low-grade equipment used limited bandwidths to about 4kHz. In [outer space](#), the communication range of free-space optical communication is currently in the order of several thousand kilometers, but has the potential to bridge interplanetary distances of millions of kilometers, using optical telescopes as beam expanders. [IrDA](#) is also a very simple form of free-space optical communications.

Secure free-space optical communications have been proposed using a laser [N-slit interferometer](#) where the laser signal takes the form of an interferometric pattern. Any attempt to intercept the signal causes the collapse of the interferometric pattern. Although this method has been demonstrated at laboratory distances in principle it could be applied over large distances in space.

# APPLICATIONS

Two solar-powered satellites communicating optically in space via lasers.

Typically scenarios for use are:

- LAN-to-LAN connections on [campuses](#) at [Fast Ethernet](#) or [Gigabit Ethernet](#) speeds.
- LAN-to-LAN connections in a [city](#). *example, [Metropolitan area network](#).*
- To cross a public road or other barriers which the sender and receiver do not own.
- Speedy service delivery of high-bandwidth access to [optical fiber](#) networks.
- Converged Voice-Data-Connection.
- Temporary network installation (for events or other purposes).
- Reestablish high-speed connection quickly ([disaster recovery](#)).
- As an alternative or upgrade add-on to existing wireless technologies.
- As a safety add-on for important fiber connections (redundancy).
- For communications between [spacecraft](#), including elements of a [satellite constellation](#).
- For inter- and intra<sup>[8]</sup>-chip communication.

The light beam can be very narrow, which makes FSO hard to intercept, improving security. In any case, it is comparatively easy to [encrypt](#) any data traveling across the FSO connection for additional security. FSO provides vastly improved [EMI](#) behavior using light instead of microwaves.

# Advantages



RONJA is a [free](#) implementation of FSO utilizing high-intensity [LEDs](#).

- Ease of deployment
- [License-free](#) operation
- High [bit rates](#)
- Low [bit error rates](#)
- Immunity to [electromagnetic interference](#)
- Full [duplex](#) operation
- Very [secure](#) due to the high directionality and narrowness of the beam(s)
- No [Fresnel zone](#) necessary

# CONCLUSION

In free-space optical communication links, atmospheric turbulence causes fluctuations in both the intensity and the phase of the received light signal, impairing link performance.

The potential for Free-space optical networking to solve communications bottlenecks is making it a popular option for reliable, broadband access. A thorough examination of the issues affecting the design of these sophisticated systems is a useful tool when evaluating Free Space Optics (FSO) systems for purchase. Systems that incorporate the most beneficial features, are well-engineered, and thoroughly tested will be top performers and provide the best value.

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