Free Space Optical Communication: A Survey on Various Modulation techniques

Pranav B. Lapsiwala[1],Priteshkumar B. Vasava[2]

[1]*Professor, Department of Electronics & Communication, Sarvajanik college of Engineering and Technology Surat (India)*

[2]*Ph.D Research Scholar, Gujarat Technological University,Ahmedabad*

Abstract*:Optical wireless communication (OWC) refers to transmission in unguided propagation media through the use of optical carriers. In this survey, we are focusing on data transmission with the help of Hybrid modulation technique. PPM and QAM will be our main focus for the Hybrid modulation technique. FSO systems are used for high rate communication between two fixed points over distances up to several kilometers. In this paper, we present an up-to-date survey on FSO communication systems. The first part describes FSO channel models and transmitter/receiver structures. In the second part, we provide details on information of classification of FSO. Specific topics include advances in modulation, channel coding, coherent FSO system, mitigation techniques and hybrid FSO systems.*

Keywords **- Free-space Optical (FSO) Communication, Channel Modeling, Optical Wireless Communication (OWC),Optical Modulation, Spatial Diversity, Channel Capacity, Channel Coding, Hybrid FSO Systems, PPM-QAM.**

I. INTRODUCTION

A. Overview of Optical Wireless Communication

Free Space Optical communication system is a system where communication takes places with the help of free space. FSO communication system use LASER or LED as a light source to generate a signal and as well as know that light travel faster in free space as compare to other mode of transmitting media. So, FSO communication system provides high speed communication and become primary choice in those fields where high speed data transmission is primary requirement along with high speed transmission it has also many advantages like as Lower Power Consumption, Last Mile access etc. as compare to other modes of data transmission which is explained later in other section of this paper.

B. Advantages and Applications of FSO

i. High Speed :-

It provides high speed communication than other mode of transmissions.

ii. Low Cost :-

As signal transmission takes places with the help of free space cable cost is eliminated and hence require low cost for data transmission.

iii. Mean Time Between Failure (MTBF) :-

Mean Time Between Failure is about of 10 years so it is like one time installment it will cost only one time for system establishment and become free for some years.

iv. License Free :-

It operates in a completely unregulated frequency spectrum and currently there is little traffic in this, so it is not likely to interfere with other transmission systems and it not requires license to operate at this frequency spectrum range.

B. Applications :-

i. Outdoor Wireless access :-

It can be access by anytime anywhere as it is wireless communication system so to outdoor connectivity feature is also available.

ii. Last - Mile Access :-

It provides long distance communication very easily and difficulties to get access of data communication at long distances become easy.

iii. Enterprise Connectivity :-

FSO system are easily installable this feature make it applicable for inter connectivity to connect two building along with that it requires less time to install a system.

iv. Back-haul :-

It can be helpful in carrying the traffic of cellular telephone from antenna towers to the PSTN with high speed data rates. [1]

v. Military applications :-

As it is secure and undetectable it can connect large areas safely so, it is suitable for military applications.

vi. Service acceleration :-

It can be useful to provide instant and fast service to customers when their fiber infrastructure is being deployed in mean time.

Table 1 :- Comparison of FSO with other mode of technologies : [2]

Features	FSO	Fiber	DSL
Deployment Time	Days to week	4-12 Months	6-12 Months
Provisioning Time	Immediate	Complex	Complex
Initial Investment	Low	High	High
Reliability	Medium	High	High
Topology/Flexibility	PP, PM, Mesh	PP, PM, Mesh	PP
Distance Limitation	200-2000 m	200 km	5.5 Km
Bandwidth/Speed	1.25 Gbps	10 Gbps	2 Mbps

I. FSO CHANNEL MODELING

- **Geometric loss**

Geological damage is caused by the divergence of the beam when the beam propagates through the atmosphere. It can be measured by deviation angle, link distance and receiver lens aperture size. The optical wave propagation model is the critical factor of the ground impulse loss. Horizontal FSO Broadcasting required Gaussian Profile for beam intensity. Horizontal FSO transmissions require a Gaussian profile for beam intensity. When the

Gaussian beam has a relatively large deviation, its statistical properties are close to the point source.

In such a case, the approximations of plane or spherical wave can effectively be used. The degree of beam divergence affects transmitter – receiver alignment and beam tracking at the receiver. Narrowness of Transmitted beam and generally small receiver field of view (FOV), building construction can effectively cause communication interrupt. Beam wander is the reason for the random deflection of the optical beam, and as a result, Beam wanders forget its original path. On the other hand, the building is the result of various factors like Thermal expansion, wind load, including small earthquakes, And vibration.

When no tracking mechanism is used at the receiver side, the misalignment loss can be alleviated by increasing the beam divergence at the transmitter. Transmitter beam Radius can be adapted to maximize average link capacity And reducing the deployment of variable wavelength outage probability using quantum cascades which reduce the effect of manufacturing lasers. For long distances (I.e., more than a kilometer), A Narrow beam should be required to avoid suffering from high Geometric loss, and An automated pointing and tracking Receiver are necessary to remove or minimize impact Pointing to errors. The building sway statistics follows an independent Gaussian distribution for elevation and horizontal directions, the radial pointing error angle is modeled by a Rayleigh distribution . [16]

The random attenuation of the channel is the product of path loss, geometric spread, pointing errors and atmospheric turbulence. Also, a Gaussian beam profile and Rayleigh distributed radial displacement at the receiver, a statistical model is derived for the misalignment loss and it takes the detector size, beam width, and jitter variance into account. The same model was used in to the effect of pointing errors on the FSO link capacity.

- **Atmospheric loss**

Transmission properties of radiation Penetrate into the visible atmosphere and are very similar in Near-IR wavelength ranges. Therefore, visibility may depend on characterized particles that absorb or scatter light for near-IR Radiation. Particles affecting visibility in Rain, snow, fog, but pollution, dust, aerosols, smoke, etc. [30]

- **Atmospheric Optical Transmission**

Characteristic particles absorb laser light energy to some extent, leading to attenuation of optical power.

For rain and snow, the size of the particles is much larger than the wavelength, and as a result, FSO transmission is relatively unaffected . In the case FSO systems are Posted in metropolitan areas less than 1 km, The attenuation value of rainfall is 3 dB / km. Only for very severe rain, attenuation may occur An issue in deployment beyond a specific distance scale Metropolitan area. For snow attenuation may occur More severe than rain because the droplet size is much larger than the raindrops. In fact, the impact of light snow to blizzard falls approximately between light rain to moderate fog .

When the particle diameter is on the order of wavelength, The resulting scattering coefficient is very high. Most harmful environmental conditions are fog and haze, because they are made of small particles Near the radius near-IR wave length. At very low levels Distance Too modest Fog conditions can increase IR signals and its Experimental tests reported 90% loss in fog condition. Transmitted power at a distance of 50 m in moderate fog .

Experimental measurement is Revealed that atmospheric attenuation is almost independent The wavelength in fog (between 785 and 1550 nm), but it depends on the fog conditions. Smog/haze particles have sizes between 0.01 and 1 micron and The range of fog

droplets is between 1 and 20 μm. The beam is proved that beam suffers from less attenuation in smog/haze conditions. Different scatter sizes affect the wavelength hence its dependence Light extinction conditions in mist and dense fog conditions . According to the Mie scattering principle, it is shown that a wavelength dependent model for attenuation the coefficient is proposed for fog and haze conditions. An important point is that RF wireless technology Those that use frequencies higher than about 10 GHz are hostile Affected by rain and slightly affected by fog. FSO channel modeling Channel mobilization bandwidth defined as inverse Channel delay propagation. In fair weather Conditions, the FSO channel has a negligible delay spread, Fog, moderate clouds, and rain can potentially be temporary Widening of optical pulses. Under moderate and dense fog, the delay is spreading. Generally limited to 50 picoseconds. In the case, the channel can effectively be considered as a frequency Non-selective starts, according to ISI. FSO link data rates, Beam scattering resulted in channel delay spread Fog or rain is practically negligible. [31][32]

- **Communication link Parameters**

✧ **BER**

We can assume that the wave must be a plane wave or a spherical wave, while the actual transmitting beam of the FSO system is a Gaussian beam, so that the effect of different transmitting beams can affect the performance of the FSO system, so BER is an important parameter. Initially from the aperture average effect without considering the turbulent internal and external scale effects, the effect of turbulent strength on the aperture average effect under the Gaussian beam condition is analysed. It has been shown that increasing the turbulent strength makes the aperture average effect more pronounced. And then, under the weak turbulent condition, the effect of propagating the beam on the improvement of BER performance by the aperture by the average effect is simulated. The results showed that the Gaussian-beam wave has a clear effect on BER performance, and saturation is reached first, followed by a spherical wave. The plane wave is relatively soft.

Under rented broadcast wave conditions, the aperture of the mean effect is essentially different. The results show that with the growing of turbulent intensity, the aperture averaging effect will become increasingly apparent. The effects of aperture averaging on BER performance under different beam conditions vary under Gaussian-beam wave conditions, the effect being most pronounced, followed by the spherical wave, and the change of plane wave is relatively slow. [17]

✧ **SNR**

Free-space optical (FSO) communication links are used for individual fading for long terrestrial links, which can result in a logo normal, gamma-gamma, or fast distribution. Signal under weak, moderate and strong turbulence. Channel estimation is also contaminated by background and electrical noise. We measure the FSO fading distribution Experimental data collected from 1550nm, 12 km long terrestrial link. Statistics background and electrical noise are found From the collected noise data. Background and electrical noise that sum to fading plus Gaussian noise.[18]

✧ **NOISE**

Noise affects data signals, which are the main part of communication. Differential type noise affects the system such as thermal noise, Johansson noise and the external field or Geo-impulse component of the system. For good better communication we have to remove noise from the data signal. Free-space optical (FSO) communication is an emerging technology that provides heavy bandwidth, license-free spectrum, and highly secure links. Avalanche photodiodes are commonly used to detect high-speed FSO signals, where the noise signal-dependent Gaussian noise represents the distribution rather than the signal-independent Gaussian noise (sine) distribution. When the channel send the information

to the receiver. We required to develop an external information transfer (EXIT) chart to measure decoder convergence with and without the effect of distribution noise. [33]

II. FSO TRANSCEIVER

a) TRANSMITTER

In FSO communication systems, a source is used as an input information signal. Optical communication requires it to be modulated on the optical carrier. This optical signal then radiates through the atmosphere towards the destination. From the receiver side, these optical signals are reassembled and then it will be converted into electrical signals using photo-detectors. The receiver processes this electrical signal in the original transmitted information.it means the reuse used to retrieve the original signal. Currently the FSO system typically operates in near-IR wavelengths, that is, from 750 to 1600 nm.

For some particular wavelength windows, 850, 1060, 1250 and 1550nm are consider as specific wavelengths for an attenuation of less than 0.2 dB/km is experienced. 850 and 1550 nm windows As a standard transmission window for fibre communication systems. 10 10m wavelength is used for better fog transmission. UV transmissions, on the other hand, are More robust against errors and blockage of the beam and There is a low sensitivity to solar and other background interference.

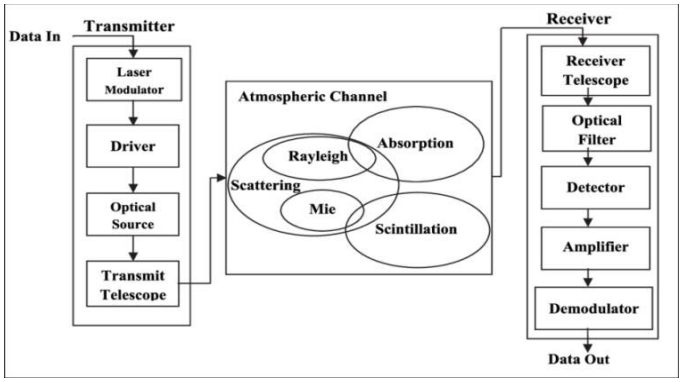


Figure 1. FSO transceiver

From the above fig. 2, the transmitter consists of an information source, a modulator, an optical amplifier and a focusing optical lens (collimator). Channel coding is not necessary, but if U need to use before the modulation. Here, the data bits are information sources. Data bits or information is first encoded and then modulated. Data information is now modulated, this information is in the form of laser light. This collector laser beam is then passed through an optical amplifier. An amplifier is greatly needed to boost optical intensity. The light beam is refocused by the collimator and then beam is going in to the transmitted. The typical optical source in FSO systems is used a semiconductor laser diode, although some manufacturers use high power LEDs with beam collimators. The optical source should deliver a relatively high optical power over a wide temperature range. In addition, it must have a long time between failures (MTBF) and the associated components must be small in footprint and have low power consumption.

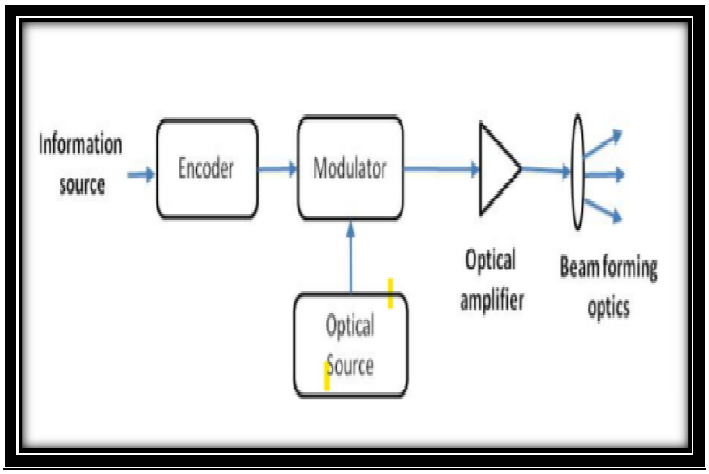


Figure 2.

As a result, vertical-cavity surface-emitting lasers (VCSELs) are used for conducting at about 850 nm, and Fabry – Perot (FP) and distributed feedback lasers are mostly used for operation at 1550 nm. The laser transmitter has some safety issues. The primary safety concern is the potential exposure of the eye to the laser beam. Several parameters have been developed to limit transmitted optical power, which is dependent on laser wavelength and parameters such as average and peak transmission power. Only a few wavelengths in the near-IR wavelength range can provide the eye safe with sufficient intensity to damage the retina. Other wavelengths are absorbed by the front part of the eye before focusing on the retina. In fact, the front-eye absorption coefficient is much higher for long wavelengths (> 1400 nm).

b) RECEIVER

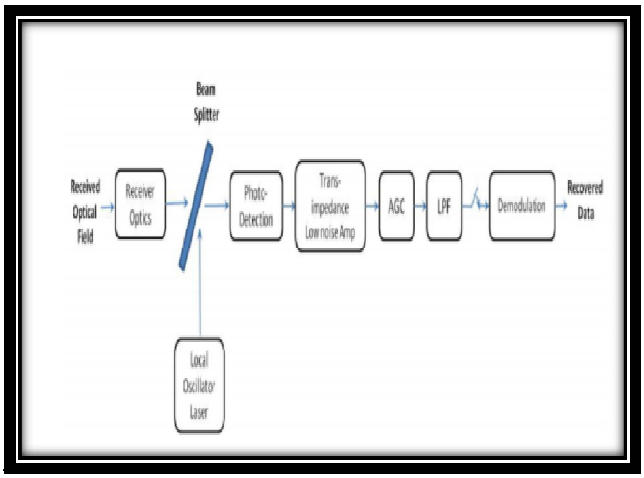


Fig 3.

FSO systems can be classified into two classes which are based on detection like non-coherent and coherent. In Coherent System (Figure 3), Can use amplitude, frequency, or phase Modulation technique. Receiver side, received this region is optionally locally mixed before photo-identification Generated optical field.

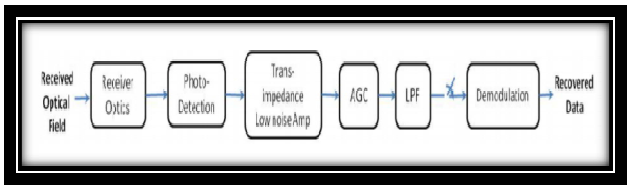


Figure no. 4 Non coherent receiver

In non-coherent systems (Fig. 4), the intensity of the emitted Light is employed to convey information. The photo-detector on the receiver side detects changes in light directly Intensity without the need of local oscillator. Although coherent systems provide the best performance in terms of background noise rejection, turbulence-induced fading, and high receiver sensitivity. Non coherent systems are commonly used terrestrial FSO links to their simplicity and low cost. At the receiver side, non-coherent system is consisting of optical filters and a lens which are used for collecting and focusing the received beam onto the photodiode. The current output of photo diode is next converted to a voltage with the help of a trans-impedance circuit. Usually a low-noise Op-Amp with a load resistor is use. Then the transmission rate, the dynamic range of the converted into electrical signal, the generated receiver thermal noise, and impedance matching with the other receiver parts. The output of the trans-impedance circuit is then filtered by low-rate filtered to limit thermal and background noise levels.

Si Photo Diodes have a maximum sensitivity around 850 nm, whereas In Ga-As Photo Diodes are suitable for operation at longer wavelengths around 1550 nm. Ge Photo Diodes are rarely used, because of their relatively high level of dark current. PIN diodes are usually used for FSO systems for a few kilometres. The main drawback of PIN Photo Detectors is that the receiver performance becomes very limited by the thermal noise. For long distance links, avalanche photodiodes are mostly used which provide a current gain thanks to the process of impact ionization. In particular, we need a relatively high voltage for Avalanche Photo Diode reverse biasing which is use for special electronic circuits. This also results in an increase in the receiver power consumption.

The optical pre-amplifiers are used in long range FSO links which improves their performance. In the 1550 nm wavelength, an Erbium-doped fiber amplifier is a good choice. Semiconductor optical amplifiers can also be used for various wavelengths (including 1550 nm). However, the problems associated with coupling to the receiver optics, especially when using a multimodal fiber are used. the optical amplifier introduces an amplified spontaneous emission noise, usually modelled as additive white Gaussian noise, which can degrade the receiver performance. when the receiver performance is limited by the electronic noise optical pre-amplification can be highly beneficial.

III. CLASSIFICATION OF FSO

FSO can be used for long distances as well as for small distance. Now we are studying about the classification of FSO system. Communication is works with the different type of techniques and/or networks, that means various ways are available for good communication. From the upper image we can say that there are mainly two types of FSO system are available. One is INDOOR SYSTEM and another one is OUTDOOR system.

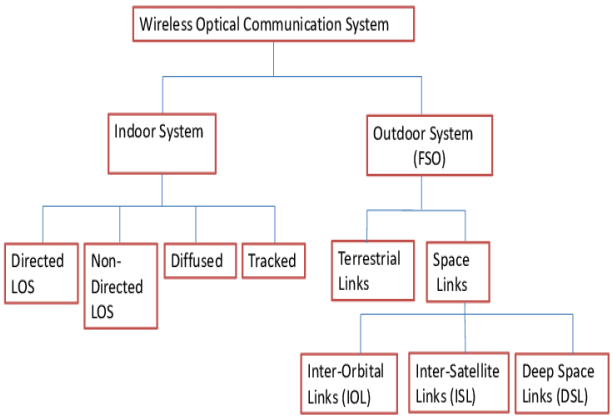


Fig 5.

we are trying to test our project which is the type OF OUTDOOR and TERRISTIAL link. We are going with the outdoor communication system. These types of systems are selected based on which type of communication we choose.[34]

Optical Wireless Satellite Networks

This system is also called OWSN. The satellite network is a wide area covering communications. This system provides very good high bandwidth communication. This system or network covers a large area of the earth. This system establishes a space network with optical links. This means that we can say that satellite network work is very useful for terrestrial residents.The satellite network depends on how long the line of sight exists. Satellite network communication is very useful for long distance communication such as an aircraft, ocean, forest etc. The types of OWSN systems are satellites for the space wind, satellites on the surface of the earth, etc.

An inter-satellite is called ISOVEC. The IsOWC system is a type of optical wireless satellite network. This system offers a wide variety of benefits such as small size, low power requirement, and a high band width. This is much easier and better than the Steam microwave satellite system. Lasers have less loss than RF signals.The system establishes a network connection between satellite and Earth stations. The system struggles with massive diffusion losses. Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellites are highly desirable for spherical links and communication function.

The OWSN system is a replacement for the current wired communication system. When communication is used in the ocean, the system is much more flexible and is a low cost comparatively wired communication network. This system has also worked for long distance communication very easily. The disadvantage of the system is that once the system is launched,We cannot change factors such as physics, link capacity, and routing strategy which are important issues that must be carefully addressed.[35]

Example of the system

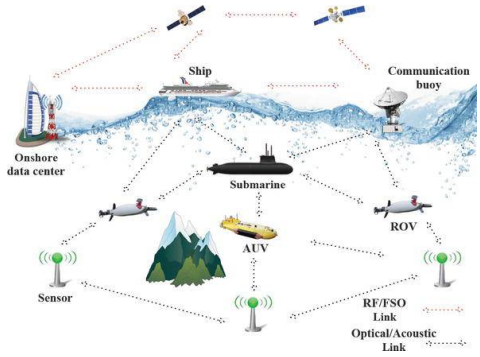


Fig 6. [36]

OPTICAL WIRELESS TERRISTRIAL NETWORK

This network system is also called OWTNs. The TERRISTRIAL network is a worldwide demand for broadband communications requiring single mode fiber networks. But this optical wireless terrestrial network system provides high data rate Internet access with mobile wireless communication. Old-fashioned high-speed communicators were used to help optical fiber networks, but users have the problem of connecting individual links. This technique is called high speed bridging technique, which has individual connection problem called its first or last mile problem. This problem is solved by this OWTN system. This system is the type of external link. This cytosine communicates between two transceivers through the atmosphere or air. Atmosphere is affected by Steposhpheric turbulence. This type of network belongs to the ground base, so it is very necessary to lose this system must be fully maintained. No one needs to be unaffected by physical obstruction. Atmospheric space can be hind infrared meter up to ten kilometers. This system establishes a connection without digging and laying optical fiber. Mobiles are also easily use this system.

Example of the system

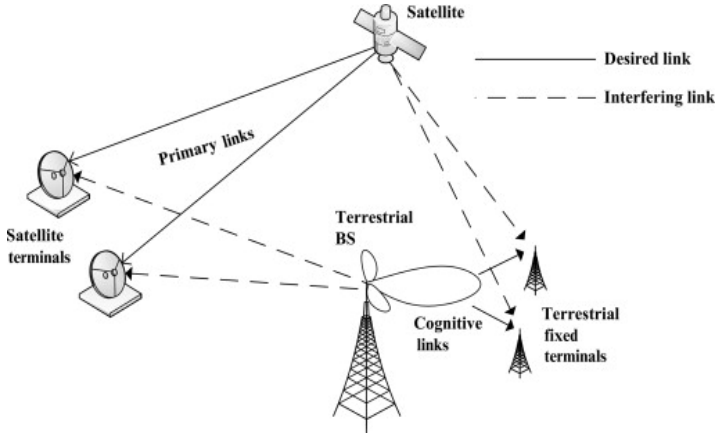


Fig 7.

OPTICAL WIRELESS HOME NETWORK

This network is a type of indoor optical wireless communication. This system is called OWHN system. Satellite wireless systems and terrestrial systems are available that provide good Gbps speed to the user but the main problems are associated with the Homo-system. The problem is that limited link in the home system, deviations and field of view and trouble is to provide good data rate and coverage in the limited link budget.

Limited network devices are used in home network system. Indoor point to point community is mostly affected by physical obstruction. Physical blockage may be temporary or it can be fixed.

This system provides wireless broadband communication in office, school, collage, association and home etc. This site requires each person to use cell which to achieve simultaneous transmission. Each cell or user has a common base station. The each and every

cell or user are connected with each other with a small range of wireless linings. Wireless links can be light, infrared or laser. All cells required to connect with the broadband for communication. Types of this site are LOS LINKS and NON LOS LINKS.

Example of the system

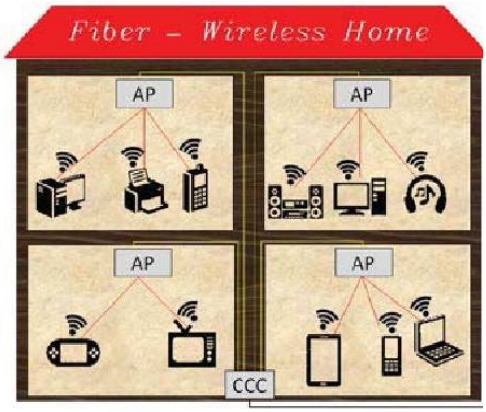


Fig 8.

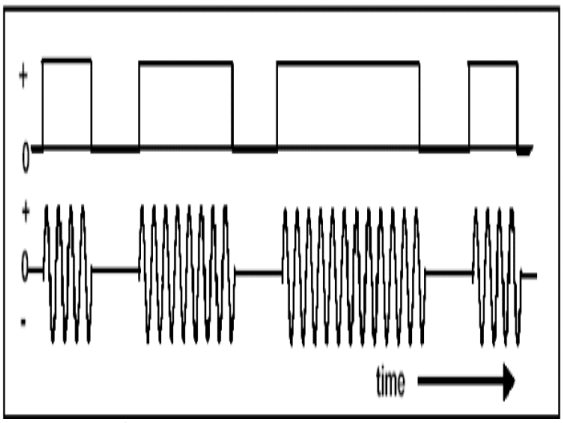


Figure 8. - ASK modulation format, (a) Binary signal, and (b) ASK modulated signal.

IV. MODULATION

The different types of modulation takes places in the optical wireless communication are amplitude modulation , Phase modulation, frequency modulation and Polarization modulation. These different types of modulation is used as per the requirement like energy efficiency, power consumption, spectral efficiency etc. with the help of modulation channel utilization and channel capacity can be increased.

1) Amplitude Shift Keying (ASK) :-

It is a type of intensity modulation of carrier signal also called as ON-OFF Keying. In

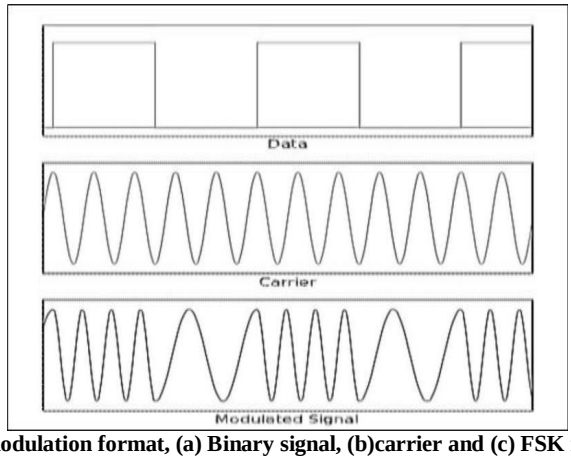


Figure 9. - FSK modulation format, (a) Binary signal, (b)carrier and (c) FSK modulated signal.

this, amplitude of carrier signal is kept changing based on the signal of digital modulation and in ASK frequency and phase of the signal are kept constant. In ASK technique carrier signal is superimposed into the original signal with binary signal. For "ON" state binary 1 is transmitted and during "OFF"state binary 0 is transmitted.

To increase the transmission capacity multilevel signaling is used in which two level binary signals are being binary signal which is represent by equation m =2^N also known as M-ary signaling.[28].

2) Frequency Shift Keying (FSK) :-

In this technique frequency of light source is switched between the two frequencies is known as Frequency Shift Keying (FSK). In this, message signal is digital and carrier signal is high frequency sinusoidal signal and frequency of carrier signal is changed according to the information signal and achieved FSK. Modulation index in FSK system is already defined and can be changed as per requirement of different modulation format, but changing in modulation index requires more compact or compressed optical spectrum and can lead towards complexity of the system.

In FSK parameter of transmission live must be match with parameters of Tx and Rx. [26][28][29]

3) Phase Shift Keying (PSK) :-

In this, information signal is digital signal carrier signal is sinusoidal signal in which phase of carrier signal is changed according to the information signal. This type of signals are very sensitive about the phase modulation produced by multichannel effect and due to this rate of error during decoding the received signal can be increased and hence instead of PSK another formats of PSK known as Differential Phase Shift Keying (DPSK), Quadrature PSK (QPSK) are being used. In DPSK signal encoding takes place deferentially means phase changing take place between two successive bits, and in QPSK coding efficiency is increased by using and different phases. DPSK and QPSK system are better modulation format as compare to PSK. [26][29]

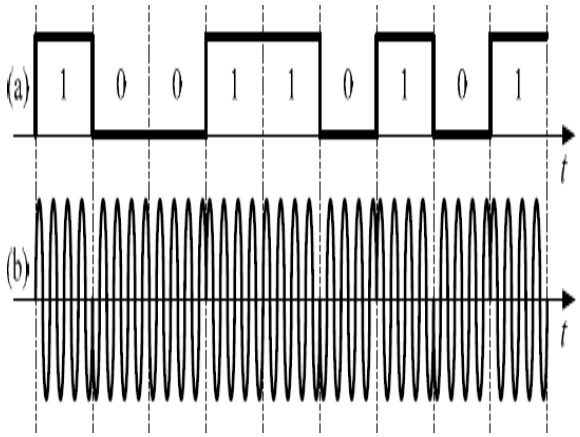


Figure 10. - PSK modulation format, (a) Binary signal, and (b)PSK modulated signal

4) Polarization Shift Keying :-

It is the capacitive modulation format. There are two polarization state present between the polarized signal and signal which is switched to generate polarized shift signal. Here a constant signal is being identified for improve the non-linear tolerance and provides a sensitivity for a better utilization of the system bandwidth, beside this differential polarization phase shift (DPoIPSK) system is introduced in which system information is encoded in polarization and phase with multilevel direct detection, and effect of non-linear polarization scattering is reduced. [29]

5) Pulse Position Modulation (PPM) :-

It is especially suited for direct detection of an optical signal which are transmitted through free space.

A logical '0'and '1'are represented by pulse present in 'first' slot and 'second' slot respectively. 4-PPM encodes two bits of signal into each four-slot symbol whose duration is and bit periods, similarly m-ary PPM extends the no. of bits represented by each of m distinctive symbols. [27]

BER equation are follows :-

a) For 2-PPM :-

$$\text{BER} = \frac{1}{2} ertc\left(\frac{\sqrt{SNR}}{2}\right)$$

b) For 4-PPM :-

$$\text{BER} = \frac{1}{2} ertc\left(\frac{\sqrt{SNR}}{\sqrt{2}}\right)$$

c) For 8-PPM :-

$$\text{BER} = \frac{1}{2} ertc\left(\frac{\sqrt{3}\sqrt{SNR}}{\sqrt{2}}\right)$$

d) For 16-PPM :-

$$\text{BER} = \frac{1}{2} ertc\left(2\sqrt{SNR}\right)$$

Table 2 :- Comparison of Different Modulation Technique [28]

Modulation Techniques	Features
OOK-NRZ	Direct detection, Moderate SNR, Low Cost, requires the adaptive threshold
OOK-RZ	Direct-detection,High sensitivity
PPM	Direct-detection, Superior power efficiency than any other base-band modulation
DPSK	Direct detection used for short distance communication
BPSK	Coherent detection,long-haul communication, powerefficiency

Table 2 :- Comparison of Different Modulation Technique [27]

Modulation Scheme	Application
BPSK	Cable modems, Deep space telemetry
FSK, GFSK	Paging, land mobile, public safety
MSK, GMSK	Global System for Mobile
QPSK, π/4QPSK	Satellite, CDMA, cable modems, TFTS
OQPSK	CDMA, Satellite
8-PSK	Satellite, aircraft, telemetry pilots for monitoring broadband video systems
16-QAM	Modems, Microwave digital

	radio
32-QAM	Terrestrial microwave
64-QAM	Broadband set top boxes, Modems,MMDS

V. DIVERSITY

Transmitter & Receiver Diversity:-

The performance of FSO communication is badly affected by atmospheric conditions like as fog, rain, dust, smoke etc. and turbulence is created by random variation in refractive indices takes place due to variations in temperature and pressure.

Due to turbulence transmitting signal strength & quality will degrade and in order to lower down the channel fading we use transmitter & receiver diversity along with such techniques like as modulation, amplification etc.

Transmitter diversity is simply to send the same message/information on the different beams which is beneficial for fading reduction at the receiver end.

In receiver diversity fading reduction can be achieved by using different small aperture at receiver end and receiver diversity is generally take places with the help of large lens at the receiver to manage intensity fluctuations which is knows as aperture averaging. [1]

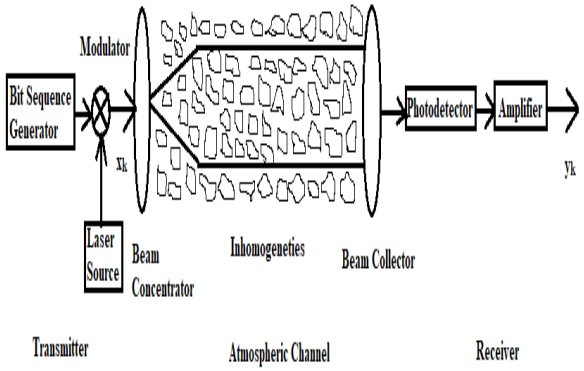


Figure 12. - T1 Representation of system model for outdoor FSO communication suffering from atmospheric turbulence [39]

Above figure represent how atmospheric turbulence affects the information/message and to remove such type of problems spatial diversity technique are used along with the modulation, amplification etc. to improve signal strength of initial information .

Spatial diversity:-

The concept of diversity is to provide multiple copies of the same transmitting signal/message to the receiver.
Spatial diversity techniques are:-

1) Single input- single output (SISO):-

It provides the simplest description of communication link between transmitter & receiver. This clearly implies that it cannot be considered as spatial techniques as here only single copy of original message is present.

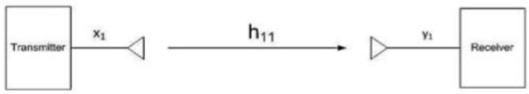


Fig 13. SISO (Single input- single output) [1]

2) Single input- multiple output (SIMO):-

It utilizes one transmitting antenna and multiples antennas at the receiving end. Thus any signal transmitted from the single transmitting antenna will achieve by all receiver antennas.

As multiple independent copies of the same message are achieved by receiver it is spatial diversity.

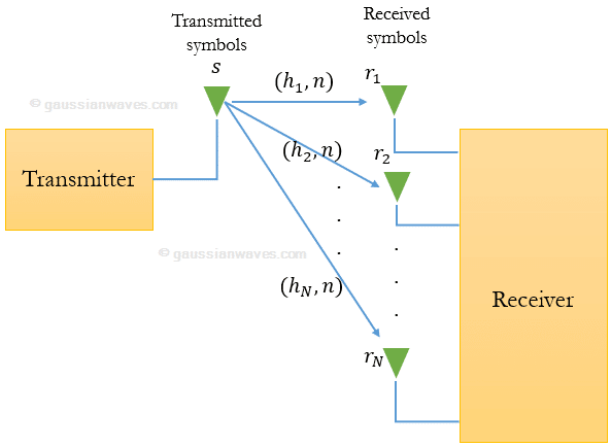


Fig 14. - SIMO (Single input multiple output)

Two combining techniques are used here:

Maximal ratio combining (MRC) and equal gain combining (EGC) both these techniques involves the use of a matched filter at the receiver to combine the received signals to combine the received signals to improve the SNR of the output. [40] [41]

3) Multiple input- single output (MISO):-

It utilizes multiple antennas at the transmitting side & single antennas at the receiver end. In this technique single message is transmitted through the entire transmitter and arrives at single receiver antenna.

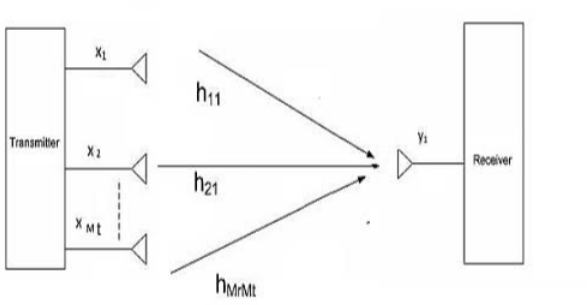


Fig 15. - MISO (Multiple input- single output)

If assuming that perfect channel information is available at the transmitter than it is possible to achieve transmitter diversity with the help of MRC & EGC at the transmitting side and applying MRC at transmitter it requires filter. [40]

4) Multiple input- multiple output (MIMO):-

It utilizes multiple antennas at both transmitting and receiving end. The common form of MIMO systems are the space-time diversity, exploiting both space and time diversity along with that MIMO technique capable of providing multiplexing i.e. allow multiple messages from different antennas and improving efficiency of the system. [40][41]

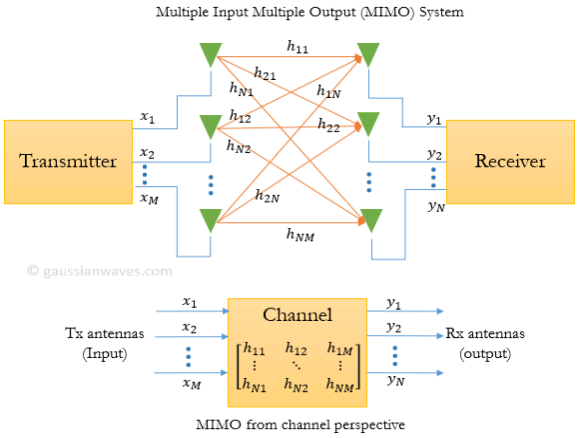


Fig 16. MIMO (Multiple input- multiple output)

VI. FSO SYSTEMS

FSO is communication system where free space acts as medium between transceivers and they should be in LOS for successful transmission of optical signal medium can be air, outer space or vaccum. This system can be used for communication purpose in hours and in lesser economy.

FSO system can be classified according to their location of transmitter, receiver and networks range.

[1] Optical Wireless Satellite Networks (OWSN)

[2] Optical Wireless Terrestial Networks (OWTN)

[3] Optical Wireless Home Networks (OWHN)

[1] Optical Wireless Satellite Networks (OWSN)

OWSNs are purpose to provide high band width because of high band width OWSNs access to end-users by making use of satellites which cover large area of earth. [3,4,5]

OWSNs can demonstrate general space determination network with optical links since satellite can support any terrestial residents anyhow of topographical limitations as long as LOS general path exits. Therefore OWSNs can offer high quality data services even to remote areas such as Island ship in the Ocean.

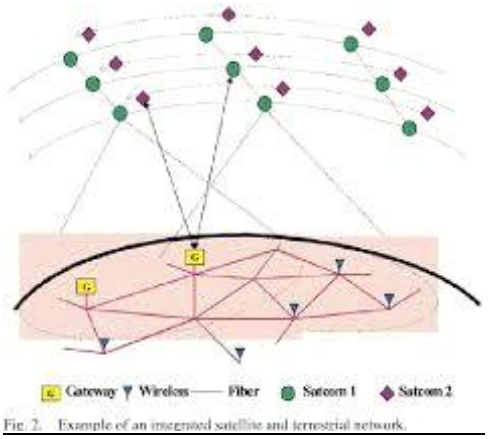


Fig. 2. Example of an integrated satellite and terrestrial network.

Fig 17.

OWSNs consists of different kinds of free general including inter satellite to satellite air and satellite to surface optical links. Inter satellite links are designated to surface optical links. Usually such links have very high data rates >= 10 Gbps. Thus ISLS can be used for global communication.

OWSNs can be another for the present wired internet, mainly for over the ocean communication that are mostly accomplish undersea fiber communication system. OWSNs do not need such communication underpinning as undersea cables and effortlessly overcome the barrier of long distance.

Military organization are also laboriously focusing on generating OWSNs required for planned and calculated functions. In May 2001 the U. S. national reconnings - sane office (NRO) launched a geosynchronous lightweight technology. The U.S. department of defence (DOD) military satellite communication (MI satcom) joint program office has a plan to fully operate the transformational satellite communication. System in 2016 as integral part of the U. S. military.[6]

[2] Optical Wireless Terrestial Networks (OWTN)

OWTNs is known as rustic FSO networks institute a point to point and LOS optical wireless connection in the middle of two transceivers constantly outdoor atmospheric turbulence channels [7,8,9,10] due to loss precondition the distance of light propagation all over free atmospheric space in from hundreds up to tens kilometers this telecommunication and becoming prime means for broadband internet entrance.

Some of the utilization's scenarios are presented below.

OWTNs can be used cross get by high data rate networks, mainly when they are geographically separated FOR instance FSO links for ship to ship building or community communications can be established without ditching and lying optical fibers. Mobile terminals can also be easily supported.

OWTNs are fruitful solutions for the “Last Mile” problems.[7] Even nevertheless optical fiber end-users who do not have their own services. OWTNs can allow a towering bandwidth connection over a large distance for distance end users.

[3] Optical Wireless Home Networks (OWHN)

OWHNs is also familiar as indoor FSO networks are sensible for wireless broadband communications inside houses and offices. OWHNs contain of cell where each cell is split spaces in the building.[8,9,11,12,13] Generally one by one cell has base station to that some terminals are connected with short range optical wireless links. Kind of infrared and light emitting diode. Any wireless optical cell should be cramped to a room necessarily to be joined to and integrated with broadband heart infrastructure.

Stationed on various propagation modes can further classify the indoor FSO links into TEO types.

[1] LOS links

[2] Non LOS links (Diffused links)

LOS need direct path linking the transmitter and receiver can simply break the LOS links. Set side by side non LOS links. LOS links accomplish superior room because of a good power estimates and the lack of multiple path propagation effects. A beam strearing mechanism however is required to assist mobile terminals with LOS links.

In no Links diffused light source is utilized to scatter a light beam during a room to take boon of multiple path propagation why reflections from all sorts of surfaces in confined space. Such as furniture, walls, ceiling and floors. As a results non LOS links are more robust when encountering obstacles however there is a trade off between networks capacity and reliability of connections here usually diffused links support a lower data rates as compared to LOS links.

OWHNs provide an effective solutions to the proliferation of communications devices and services in offices and home networks. OWHNs can provide sufficient data rates and channels capacity at low cost and thus strong candidates for future home networks however it is challenging to provide seamless roaming service to portable equipment since light mediums cannot penetrate cell boundaries. [14,15]

VII. COHERENT FSO SYSTEMS

In coherent system message signal is encoded on the optical carrier amplitude and phase whereas received beam at the receiver end is combined with local oscillator (LO) beam after mixing beam with local oscillator (LO) beam signal is amplified and detection process is limited by shot noise along with this coherent detection is useful to remove the background noise & interference another interesting property of coherent system is that information can be sent on the amplitude or phase of the optical field which become helpful to improve efficiency of the system.[1][38]

In coherent receivers there are two ways for signal detection:-

I. Homo-dyne signal detection:-

This technique provide better detection of receiving signal but it requires an accurate, optical PLL (Phase Locked Loop) and hence very expensive to implement.

In this technique receiver demodulates the original optical signal directly to the baseband because of local oscillator laser frequency is synchronized to the optical carrier frequency but practically it becomes unstable.

So, as explain earlier there are some limitations in homo-dyne technique as a result hetero-dyne technique become more beneficial.

II. Hetero-dyne signal detection:-

It is a method of extracting information which is encoded as modulation of the phase, frequency or both of electromagnetic radiation in the wavelength band.

In this technique optical signal is first converted into the electrical signal with intermediate frequency.

The main advantages of coherent FSO system with phase noise compensation is that it they are capable of removing background noise, higher sensitivity and improved spectral efficiency. [1][38]

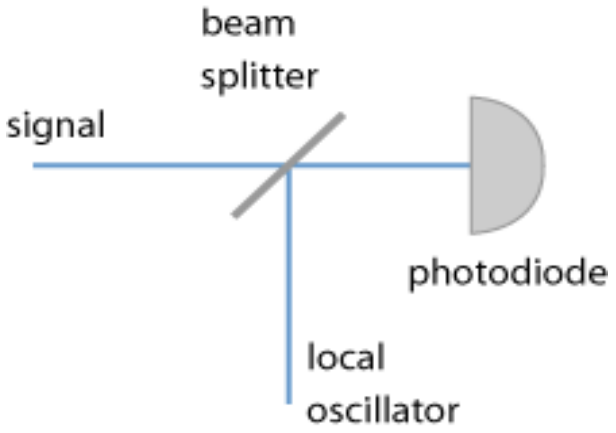


Figure 18. - Setup for optical hetero-dyne detection

It signifies more than one frequency is present where as in homo-dyne signifies only for one frequency presence.

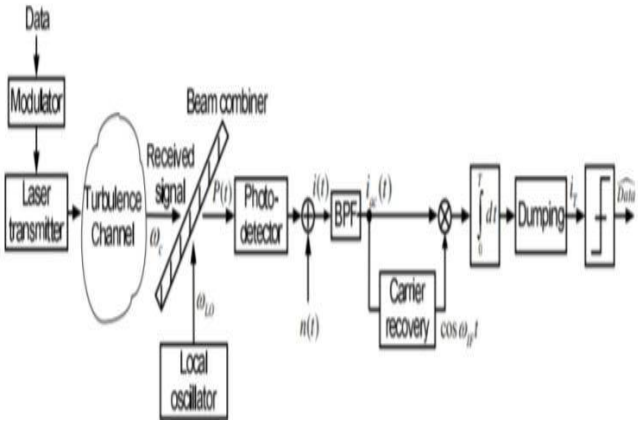


Figure 18. - Coherent free-spae optical model system. [38]

It involves optical signal & local oscillator (LO) waves but mixing product is an electrical signal. The mixing signal is not obtained by mixing the signal but obtained by detecting the linearly super imposed waves with a square-law photo detector i.e. photodiode.

The resulting photo-current is proportional to the total optical intensity, thus to the square of the total electric signal amplitude using strong local oscillator the hetero-dyne signal resulting from a weak input can be much powerful than initial information signal, hence hetero-dyne detection provides a signal gain.

VIII. MITIGATION TECHNIQUES

Mitigation Techniques Is Known As Hybrid Modulation Techniques.Hybrid Modulation Techniques Which Is A Combination Pulse Amplitude Modulation Along With Phase Modulation .

In Radio Over Fiber Technology The Optical Network Capacity Is Integrated With The Wireless Network. Main Objective Of This Work Is To Enhance The Performance Behavior Of Optical Fiber Communication System In Terms Of BER ,Received Power And Q-Factor .The Proposed Combined Modulation Technologies , Such As Pulse Amplitude Modulation Pulse Width Modulation (PPM-QAM), Digital Pulse Interval Modulation (DPIM), Pulse Amplitude Frequency Modulation (PAFM), Quadrature Pulse Position Modulation (QPPM), Multiple Pulse Position Modulation Quadrature Amplitude Modulation (MPPM-QAM) Are Used To Meet This Objective The Input Data Are Used For Modulating The Electrical Carrier Signal With A Frequency Of 250 And 255GHz.

Some Of The Modulation Techniques Are Explain In Brief As Below.

OFDM [ORTHOGONAL FREQUENCY DIVISON MULTIPLEXING]

In Telecommunications, Orthogonal Frequency-Division Multiplexing (OFDM) Is A Type Of Digital Transmission And A Method Of Encoding Digital Data On Multiple Carrier Frequencies. OFDM Has Developed Into A Popular Scheme For Wide-band Digital Communication, Used In Applications Such As Digital Television And Audio Broadcasting, DSL Internet Access, Wireless Networks, Power Line Networks, And 4g/5g Mobile Communication[23].

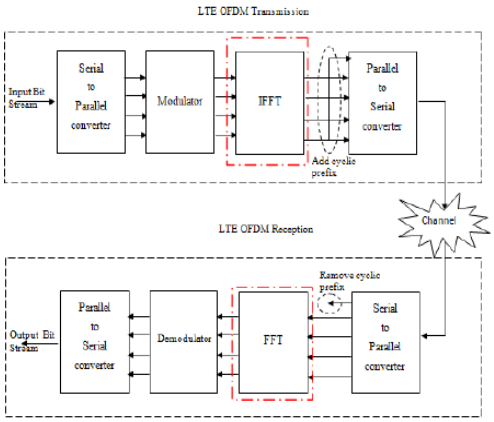


Fig 19.

OFDM Is ISA Design Of Signal Waveform Or Modulations That Deliver some Important Use full For Data Links .

Accordingly OFDM Is Utilize For Lot Of Recent Wide Bandwidth And High Data Rate Wireless Systems Along With Cellular Telecommunications And Many More.

Reality That OFDM Uses Huge Numbers Of Carriers Each Carrying Low Bit. Means That Is Very Resilient To Select As Well Interference And Multipath Effect As Well Providing A High Degree Of Spectral Efficiency.

Early Systems Using OFDM Found The Processing Required For The Signal Format Was Relatively High, But With Advances In Technology, OFDM Presents Few Problems In Terms Of The Processing Required.

Some of OFDM advantages are shown below.

- High spectral efficiency as compared to other double Side-band modulation schemes, spread spectrum, etc.
- Can easily adapt to severe channel conditions without complex time-domain equalization.
- Robust against narrow-band co-channel interference.
- Robust against inter-symbol interference (ISI) and fading caused by multipath propagation.
- Efficient implementation using fast Fourier transform.
- Low sensitivity to time synchronization errors.
- Tuned sub-channel receiver filters are not required (unlike conventional FDM).
- Facilitates Single Frequency Networks (SFNs) .

QAM [QUADRATURE AMPLITUDE MODULATION]

Quadrature Amplitude Modulation (QAM) Is The Name Of A Family Of Digital Modulation Methods And A Related Family Of Analog Modulation Methods Widely Used In Modern Telecommunications To Transmit Information. It Conveys Two Analog Message Signals, Or Two Digital Bitstreams, by changing (modulating) the amplitudes of two carrier waves, using the amplitude-shift keying (ASK) digital modulation scheme or amplitude modulation (AM) analog modulation scheme. The two carrier waves of the same frequency are out of phase with each other by 90°, a condition known as orthogonality or quadrature. The transmitted signal is created by adding the two carrier waves together. At the receiver, the two waves can be coherently separated (demodulated) because of their orthogonality property. Another key property is that the modulations are low-frequency/ low-bandwidth wave forms compared to the carrier frequency, which is known as the narrowband assumption [25].

Advantages Of QAM :-

- Doubling The Effective Bandwidth.
- Bit Rate Is Increased Without Increasing The Available Bandwidth.
- More Number Of Information Can Be Transmitted.

- QAM Signal Can Be Analog Or Digital In Nature.
- QAM SIGNAL CAN BE ANALOG OR DIGITAL IN NATURE.

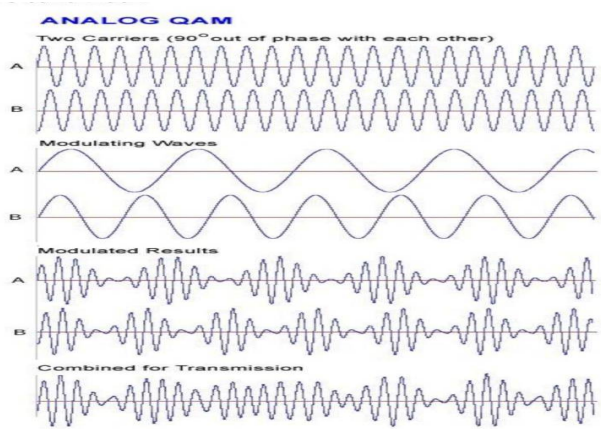
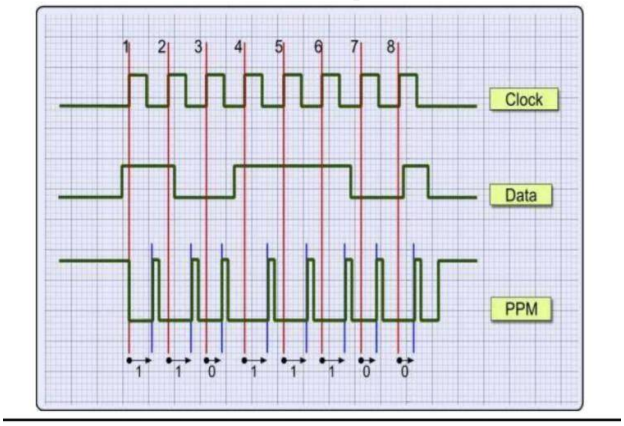


Fig 20.

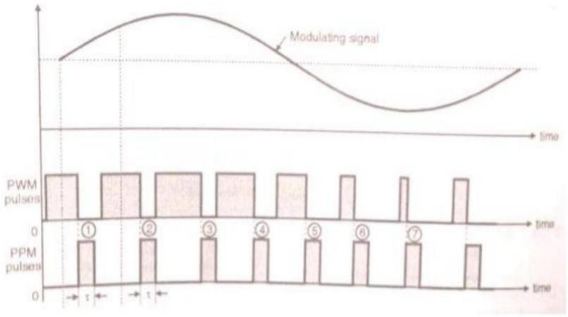
PPM [PULSE POSITION MODULATION]

It Is The Modulation Technique In Which Amplitude And Width Of Pulses Is Kept Constant Whereas The Position Of Each Pulse Is Varying According To The Amplitude Of The Sampled Value Of The Modulating Signal.

Pulse-Position Modulation (PPM) Is A Form Of Signal Modulation In Which M Message Bits Are Encoded By Transmitting A Single Pulse In One Of Display Style 2^{M}Possible Required Time Shifts. This Is Repeated Every T Seconds, Such That The Transmitted Bit Rate Is Display Style M/T Bits Per Second. It Is Primarily Useful For Optical Communications Systems, Which Tend To Have Little Or No Multipath Interference[20,21,24].



(a)Fig 21.



(A) Fig 22.

DPSK-FM

DPSK-FM Modulation Is One Of The Hybrid Modulation Formats In Optical Communication Systems. In This Modulation, Pseudo-Random Signal Is first Modulated By Di□erential Phase Shift Key Modulation With A Carrier Of 250 GHz. It Is Then Again Modulated By Analog Frequency Modulation By 255 GHz Passing Through A Band-Pass Cosine Squared filter. The Number Of Users Can Be Increased By Allocating A Carrier Frequency Of 5 GHz, Where Combiner Or Coupler Is Used To Add The User With Equal Power Is Then Modulated By An Optical Electro-Absorption Modulator. This Measurement Is Done With Vertical Cavity Surface Emitting Laser (VCSEL) Used As A Laser Source At 193.1 THz[22]. The Optical Modulated Signal Is Then Transmitted Through A Single-Mode fibre And At The Receiver End, The Signal Is first Amplified And Then Fed To The Photodetector Avalanche Photo Diode (APD) Through A Butter-worth filter Of 10 GHz Bandwidth. The Unwanted Electrical Signal Along with Their Harmonics Is filtered Through Low-Pass Bessel filter. This filtered Signal Is Further Fed To The Signal Conditioning And Retrieving 3R Generator And The Original Signal Can Be analyzed Through Eye Diagram, Bit error Analyzer And Electrical Power Meter.

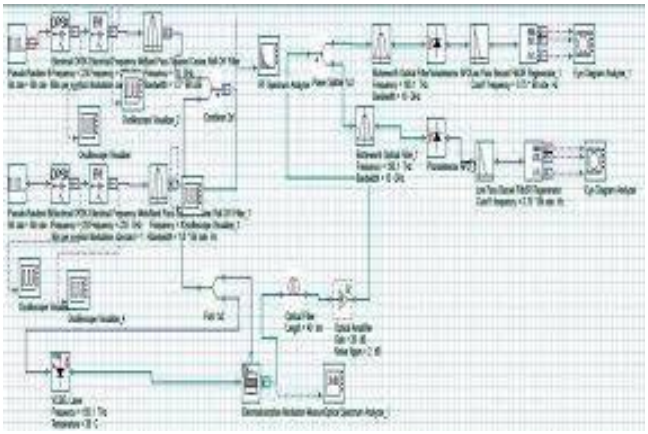


Fig. 23

QAM-FM

QAM-FM Modulation Is One Of The Hybrid Modulation Formats In Optical Communication Systems. At first, The Pseudo-Random Signal Is Modulated Using QAM

With A Carrier Of 250 GHz And Then Again Modulated By Analog Frequency Modulated By 256 GHz Passed Through Bandpass-Squared Cosine filter And The Number Of Users Can Be Enhanced By Allotting 5 GHz Carrier Frequency. The Optical Combiner Is Used To Add Users With Equal Power, Which Is Then Modulated By An Optical Electro Absorption Modulator. The VCSEL Method Is Used For The Laser As Optical Source At 193.1 THz. The Optical Modulated Signal Is Transmitted Through Single-Mode fibre And At The Receiver End The Signal Is first Amplified and then fed to the photodetector Avalanche photodiode(APD)Through a butter worth filter Of 10 GHz Bandwidth. The Unwanted Electrical Signal Along With Their Harmonics Is filtered Through Low-Pass Bessel filter. This filter Signal Is Fed To Signal Conditioning And Retrieving 3R Generator And Original Signal Can Be Analyzed Through Eye Diagram, Bit Error Analyzer And Electrical Power Meter.

IX. CONCLUSION

A brief survey of the "Data Communication using FSO" has been presented in this introductory article. This survey paper focused on the different parameters in communication using FSO like as data transmission rate, efficiency, power consumption, distance, cost, bandwidth efficiency etc. Beside this there are several much more advantages of FSO as compare to other mode of data transmission.

The advantage of FSO links results from the last mile access at lower cost & lower power consumption than other mode of data transmission apart from these laser as a light source provides high frequency, coherency & low divergence of the laser beam which provides the efficient delivery of information to a receiver and provides the high information carrying capacity besides this FSO links mainly affected by atmospheric changes which results fluctuations in optical signal at the receiver end. To improve reliability and strength of optical signal different types of techniques are being used like as hybrid FSO systems to avoid loss of information.

After considering all its advantages and disadvantages it concluded that " Data Communication using FSO" can be emerged as very efficient way for data transmission at very high speed at lower cost and it can be implemented in those fields where secure high speed data transmission is primary requirement.

REFERENCES

[1] Mohammad Ali Khalighi, Senior Member, IEEE, and Murat Uysal, Survey on Free Space Optical Communication: A Communication Theory Perspective, IEEE Commun. Surveys & Tutorials, vol. 16, no. 4, 2014

[2] M. N. O. Sadiku, S.M. Musa and Sudarshan R. Nelatury, Free Space Optical Communication: An Overview, European Scientific, vol. 12, no. 9, Feb. 2016

[3] J. Grubor, S. Randel, K.-D. D. Langer, and J.W. Walewski, "Broadband information broadcasting using LED-based interior lighting," IEEE/OSA Journal of Lightwave Technology, vol. 26, no. 24, pp. 3883– 3892, Dec. 2008

[4] Infrared Data Association (IrDA),http://www.irda.org

[5] T. Komine and M. Nakagawa, "Fundamental analysis for visible-light communication system using LED lightings," IEEE Transactions on Consumer Electronics, vol. 50, no. 1, pp. 100–107, Feb. 2004.

[6] H. Elgala, R. Mesleh, and H. Haas, "Indoor optical wireless communication: Potential

and state-of-the-art," IEEE Communications Magazine, vol. 49, no. 9, pp. 56–62, Sept. 2011.
[7] R. Lange, B. Smutny, B. Wandernoth, R. Czichy, and D. Giggenbach, "142 km, 5.625 Gb/s free-space optical link based on homodyne BPSK modulation," Proceedings of SPIE, Free-Space Laser Communication Technologies XVIII, vol. 675, 2006.
[8] B. Smutny, H. Kampfner, G. Muhlnikel, U. Sterr, B. Wandernoth, F. Heine, U. Hildebrand, D. Dallmann, M. Reinhardt, A. Freier, R. Lange, K. Bohmer, T. Feldhaus, J. Muller, A. Weichert, S. Seel, R. Meyer, and R. Czichy, "5.6 Gbps optical intersatellite communication link," Proceedings of SPIE, Free-Space Laser Communication Technologies XVIII, vol. 7199, Feb. 2009.
[9] "Laser comm: That's a bright idea," Goddard Space Flight Center,NASA, http://svs.gsfc.nasa.gov/vis/a07000/a01700/a01736/.
[10] . Y. Tanaka, T. Komine, S. Haruyama, and M. Nakagawa, "Indoor visiblelightdatatransmissionsystemutilizingwhiteLEDlight," IEICE Transactions on Communications, vol. E86-B, no. 8, pp. 2440–2454, Aug. 2003.
[11] "European Data Relay System (EDRS)," ESA, http://www.esa.int/Our Activities /Telecommunications Integrated Applications/EDRS.
[12] J. M. Kahn and J. R. Barry, "Wireless infrared communications," Proceedings of the IEEE, vol. 85, no. 2, pp. 265–298, Feb. 1997.
[13] M. Kihl M. L. Sichitiu, "Inter-vehicle communication systems: A survey," IEEE Communications Surveys & Tutorials, vol. 7, no. 2, pp. 88–75, July 2008.
[14] F. Hanson and S. Radic, "High bandwidth underwater optical communication," Applied Optics, vol. 47, no. 2, pp. 277–283, Jan. 2008.
[15] C. Gabriel, M. A. Khalighi, S. Bourennane, P. L´eon, and V. Rigaud, "Monte-carlo-based channel characterization for underwater optical communication systems," IEEE/OSA Journal of Optical Communications and Networking, vol. 5, no. 1, pp. 1–12, Jan. 2011.
[16] S. Arnon, "Effects of atmospheric turbulence and building sway on optical wireless communication systems," Opt. Lett., vol. 28, no. 2, pp. 129– 131, Jan. 2003 , X. Liu, "Free-space optics optimization models for building sway and atmospheric interference using variable wavelength," IEEE Trans. Commun., vol. 57, no. 2, pp. 492–498, Feb. 2009. , S. Arnon, "Optimization of urban optical wireless communication systems," IEEE Trans. Wireless Commun., vol. 2, no. 4, pp. 626–629, Jul. 2003.
[17] https://ieeexplore.ieee.org/document/6025476

[18] https://sci-hub.tw/https://ieeexplore.ieee.org/document/5728747

[19] https://www.researchgate.net/publication/321654200_Analysis_of_Free-Space_Optics_ Development

[20] K. T. Wong (March 2007). "Narrowband PPM Semi-Blind Spatial-Rake Receiver & Co-Channel Interference Suppression" (PDF). European Transactions on Telecommunications. The Hong Kong Polytechnic University. 18 (2): 193–197. doi:10.1002/ett.1147. Archived from the original (PDF) on 2015-09-23. Retrieved 2013-09-26.

[21] Yuichiro Fujiwara (2013). "Self-synchronizing pulse positionOverview modulation with error tolerance". IEEE Transactions on Information Theory. 59: 5352–5362. arXiv:1301.3369. doi:10.1109/TIT.2013.2262094.

[22] Thakur, R., &Mudgil, S. (2017, Jan-June). Radio over fibre for wireless communication. International Journal of Electrical & Electronics Engineers, 9(1), 111–118.

[23] https://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiplexing.

[24] https://en.wikipedia.org/wiki/Pulse-position_modulation.

[25] https://en.wikipedia.org/wiki/Quadrature_amplitude_modulation.
[26] Shashi Jawla ,R.K.Singh, "Different Modulation Formats Used In Optical Communication System"IOSR Journal of Electronics and Communication Engineering (IOSR-JECE), e-ISSN: 2278-2834,p- ISSN: 2278-8735.Vol 8, Issue 4 (Nov. - Dec. 2013)

[27] R. Pradeep, K. Ravikumar, S. B. Umesh,"Comparative Analysis of Different Modulation Technique for Free-Space Optical Communication" International Research Journal of Engineering and Technology (IRJET),Vol: 05 Issue: 03- Mar-2018

[28] Shadbhawana Jain and Shailendra Yadav, "A Survey Paper on Digital Modulation Techniques",
InternationalJournalofComputerSciencesandEngineering,Vol-3,,Issue-31/Dec/21015

[29] A. Sree Madhuri, GovardhaniImmadi, V.Mounika, A.TarunTeja, T.Aakash, N.SaiSrinivasa,"Performance Evaluation of Free Space Optics Using Different Modulation Techniques at Various Link Ranges"International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249-8958, Volume-8 Issue-4, April 2019

[30] https://ieeexplore.ieee.org/document/6844864

[31] https://ieeexplore.ieee.org/document/8067957

[32] https://ieeexplore.ieee.org/document/6844864

[33] https://link.springer.com/article/10.1186/1687-1499-2014-102

[34]https://www.researchgate.net/publication/328370915_Classification_Framework_for_Free_Space_Optical_Communication_Links_and_Systems
[35]
https://www.researchgate.net/publication/320870265_Analysis_of_Inter-Satellite_Optical_Wireless_Communication_System
[36]
https://www.intechopen.com/books/optical-communication-technology/challenges-and-opportunities-of-optical-wireless-communication-technologies
[37] https://ieeexplore.ieee.org/document/5735025
[38] MingboNiu, Julian Cheng and Jonathan F. Holzman, "Terrestrial Coherent Free-Space Optical Communication Systems."
[39] Literature Review : A Survey on FSO System.
[40] R. Deepa, Dr. Baskaran, Pratheek Unnikrishnan, aswath Kumar, "Study Of Spatial Diversity Schemes In Multiple Antenna Systems."
[41] Ashutosh Rastogi, H. Katiyar. "Overview of Diversity Combining Techniques & Cooperative Relaying in Wireless Communications.