EXPERIMENTAL EVALUATION AND DETERMINATION OF FREE SPACE OPTICAL LINK PERFORMANCE USING DIFFERENT LASERS AT DIFFERENT RAIN CONDITIONS

A thesis submitted towards partial fulfillment of the requirements for the degree of

Master of Technology in Laser Technology

Course affiliated to Faculty of Engineering and Technology and
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submitted by

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CERTIFICATE OF RECOMMENDATION

WE HEREBY CERTIFY THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY**INDRANUJ JOARDAR**ENTITLED**EXPERIMENTAL EVALUATION AND DETERMINATION OF FREE SPACE OPTICAL LINK PERFORMANCE USING DIFFERENT LASERS AT DIFFERENT RAIN CONDITIONS** BEACCEPTED IN THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF TECHNOLOGY IN LASER TECHNOLOGY DURING THE ACADEMIC SESSION 2018-2019.

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CERTIFICATE OF APPROVAL **

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The author hereby declares that this thesis contains original research work by the undersigned candidate, as part of his **Master of Technology inLaser Technology** studies during academic session 2018-2019.

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CHAPTER 1:INTRODUCTION

1.1. General introduction

Brisk use of mobile and data services into the daily are rising quite notably which are leading to enormous rise in demand for a higher bandwidth and flawless communication. The RF communication systems are discovering it not easy to cope up with the current surge in requirement for the enhanced data rates. This is mainly because of enormous cost which is associated with the situation of high capacity RF systems, right from the buying of costly spectrum to the installing and maintaining of the hardware.

Optical wireless communication has been known to humanity for centuries, as an example of the war strategies in military posts, Alexander's photo phone or the more recently creative application of it such as NASA's inter space satellite communication links. This is all possible and operational just because of its operating bandwidth; optical links by default have huge data and bandwidth capacity. The main motivation was to make a plan where seamless communication can be allocated with surplus bandwidth, and this make the humanity to see the untapped potential of this particular field of communication, which is Free Space Optical communication.

The FSO links surpass a conventional RF links when put side by side in terms of technological scale like data speed, privacy, security, cost and security, etc. but FSO have lengthy way to go before it can actually complement or even replace the RF system. The explanation for this is the volatile manner of atmosphere which causes channel fading and can cause many problem as the link of the system are also hampered.

FSO systems will thrive in sites like mountainous regions where the fiber applying system would be a dangerous job, or even in demanding metropolitan where the roads cannot be tampered. Mainly in such situation a FSO system can, not only demonstrate to be particularly useful but also can be cost effective too. In occurrence of natural or man-made adversity the FSO links can be used to give an immediate or temporary connectivity, lacking much of complicated hardware as it can be done in a condition, as the FSO links are established to provide a direct connectivity to do task and other maneuvers where the RF system is collapsible.

However, the FSO machinery itself is still in its early stage with a lot of challenges and problems to overcome before it is being effected to normal customers in every household. The atmospheric instability should be dealt with to overcome and exceed in this field. However with arrival of new technologies, and semiconductor lasers, scattering and fading effects caused by atmospheric turbulences may be conquered.

1.2. Motivation of the present work

In this thesis, the study of the loss of power and modulated frequency is measured at a particular distance, with the help of artificial rain simulation. The artificial rain simulator is created with the sole purpose of conducting these experiments only. In this thesis a great emphasis is given on the decaying effect of laser power with respect to distance, and also the readings are compared with dark room and in normal condition. This is done to have a comparison between the powers of the laser being used in sunlight or any other artificial light with the laser being used in a dark room. A study is also conducted in later chapter in this thesis, to have a view of the change in power in case of modulation or not. As it is very important to have a in depth knowledge on this topic just to overcome many atmospheric challenges.

Another study is conducted in this thesis, as rain is one of the most important factors of attenuation in FSO system, thus artificially rain is created to observe the drop of attenuation by using laser at a particular distance. As the rate of attenuation of laser is fairly unknown to the world; for that a number of lasers are used with different wavelength ranging from 450nm to 980nm. The selection of lasers are done in such a way that it can cover the range of spectrum, as 450nm - purple visible laser, 532nm - green visible laser, 638nm - red visible laser 808nm and 980nm - infrared invisible laser.

The purpose of conducting these experiments are very important for the better understanding of the nature, rate and pattern of attenuation of laser.

1.3. Literature Survey

The credibility of the experiment is derived by the utilization of the knowledge absorbed by reading following scientific papers and journals about free space optical communication, attenuation, laser, link budget, and other parameters which are immensely important for the following experiment and findings.

Eswaravaka Mahesh Reddy *et al.*[1] described the demand on communication network as the increases for bandwidth change the scenario of the communication world and influenced the need of wireless communication and the free space communication with increased bandwidth and other advantages over the normal fiber optics communication system. The scientific paper also hints on some major systematic problems and parametric problems regarding free space communication which are not solved or improved, a proposed system of MQAM(M=16) being used as to show which type of modulating way is beneficial for the outdoor environment and also for multiple users. The paper has also provided insight on the data transmission in longer distance as it shown less loss of data due to high attenuation rate .

Abu Bakar Mohammad [2] discussed about the through applications of the free space communication system its advantages and disadvantages of the system. The main focus of the scientific paper was to first analyzed and identified the problems of the free space communications and minimized the existing problem. The main problem identified by the paper was the problem of data attenuation which is occurred due to rain, and the effect of scintillation effect on free space communication. To overcome this problem a unique system was developed as they have successfully managed to incorporate not only the use of one single beam of diode laser but multiple usage of the diode laser. This process was done to observed the effect which occurred due to the rain fall and other parameters of attenuation in the conduction of the experiment. The experiment was done at a distance of 1141.2 meter between two buildings and in total of 4 different beam was used. The whole experiment was conducted with single beam to observe the notion of the solution, then it was conducted with 4 beam in a multiplexing method. The accumulated result was very promising as the optical power was measured and the rate of the transmission was more than the data received in the case of the single beam. The basic reason behind the improvement of the data was the rate of blockage in the link which was being established in the whole process but in the case of the multiple beam process there were less chances of blockage in signal, as the blockage of all 4 beam simultaneously is highly unlikely thus giving a more added advantage in this process. In this paper the tackling of the last mile problem and the different weather conditions which were very problematic for free space communication was also improved by the Hybrid wavelength division multiplexing.

SURIZA A.Z *et al.*[3] discussed the potential behind the free space communication world and its leading advantages over the fiber optical communication system but with the stated influence of the free space optical system there are some huge drawbacks which were also discussed in this paper. The main problem which was being discussed in this particular paper was the attenuation which were being formulated due to rain. There were few rain models which are being introduced to this scientific world but those model of rain attenuation are fully based on the rain climate of the different section of the world where the rain was very low. Thus in this paper the required experiment was done in a tropic region which has a rain expectancy higher than the region climate of the rain model, thus pointing to that fact the rain model was valid for every region of the world or not . As the experiment was conducted with a year on approach the required data was reveling as the rain model was not matching with recorded data by the experiment conducted in the tropical region. Thus, making it very difficult to measure the very exact attenuation rate of the system so as to overcome the predicted rain droplet size and the intensity of the rain varying tremendously. As the whole process was conducted in the time period of a year some of the data was also lost in the process resulting in the inefficiency of the recorded data to showcase the exact reason of rain attenuation.

YamacDikmelik*et al.*[4] measured the inter-sub band absorption loss as Mid-infrared quantum cascade lasers which actually operates on the normal function as in continuous wave at room temperature and have a high power levels as it also have a high wall plug efficiencies. In this paper they have also calculated the waveguide loss in this paper for the two high-performance mid-infrared quantum cascade laser designs. The laser has the inter subb and absorption loss which makes it very important of the waveguide loss for these structures. In this paper the main emphasis was given on the improvement of the wave guide loss as the loss of that parameter have huge effect on the current densities as it limits the efficient extraction of generated light out of the laser cavity. In this paper the resultant feature described as the conduction band diagram for a QCL structure which is made to have less voltage defect for the improvement of voltage efficiency.

Martin Grabner *et al.*[5] discussed the technology achievements of the free space optical communications and the merits of which, it has the upper hand on other forms of communication which are radio frequency and fiber optics. But in this paper the technical drawbacks of free space communication were also uphold like the atmospheric attenuation as they have mainly discussed in this paper. In this paper multiple scattering of light in atmospheric hydrometer was numerically simulated and presented. The paper has also used the concept of Mie scattering and mount Carlo method as to find the relation of the optical attenuation and the physical parameter of hydrometeors. The hydrometeors were also described by their drop size distribution (DSD)in this particular paper, as they have formulated some of the reasons for which desired data may not be recorded as there are many way of attenuation which can hamper the experiment. The paper has also performed the DSD simulation on the concept of rain as to found out the signal attenuation rate with the help of classical Marshal–Palmer (MP) model but they have found out that distro-meter measurements also decrease as the drop number density of the smallest drops in which a slightly modified MP model was used in this particular paper. The relation between rain droplet size and the geometric scattering is also mentioned as the simulation results were discussed. Another simulation was also conducted with DSD of fog and the simulated experiment was done. The result of the rain simulation hinted that optical attenuation which occurs due to rain has a direct relationship with the intensity of the rain rate and the size of the rain droplet. They have concluded that the multiple scattering attenuation is less than the single scattering attenuation in both the cases of the rain simulation and fog simulation. They have also concluded that in dense fog, attenuation is also lesser but the comparative difference between single and multiple scattering calculations were not that great when compared with rain. The primary attributing factor is the different sizes of droplets in rain and fog.

Suriza Ahmad Zabidi *et al.*[6] proposed a simulated free space optical communication setup 1000 meter and 5000 meter of distance with a laser of wavelength 8502 nm, as there were many model and experiment done on the field of free space optical communication in temperate region but there are very few experiments and weather attenuation model created under tropical region . As the tropical region receives a significant large amount of rainfall over monsoon season thus making it very hard to formulate under the typical temperate region based models.In this paper they have focused on the theoretical analysis and the simulation result of the different weather condition attenuations which had effected on FSO link performance. The paper has also given in depth knowledge about the fact of predictable attenuation and unpredictable attenuation of the experiment. As the predictable attenuation contents geometric attenuation and molecular attenuation, these parameters are virtually bound to occur during the course of the conducted experiment. They have also mentioned the unpredictable attenuations such as atmospheric, haze, rain attenuation and scintillation with this the experimental idea was proposed.

DhanyaDevarajan*et al.*[7] proposed a Lasercom or a laser communication prototype system mainly for the satellite communication as the laser communication has many merits over its contest like the means of radio frequency and other types. As the system consists of prospective features like terahertz transmission, compact Size, Weight and Power (SWaP) components, which can be a divisive issue in designing space missions. But the lasercom also comes with its disadvantages as it is very expensive, and the atmospheric conditions are to be considered as an optimum loss phase factor. The laser com also requires line of sight in all conditions as to communicate data, thus ensuing in pointing loss. In this paper they have proposed a test bed prototype of the laser com which can be used in the communication of the deep space communication**.** As the test bed shared with an optimizer, named as Lasercom System Optimizer (LSO) that helps the system designer to calculate and create an optimum set of the design parameter values.The paper also discussed the design, work course, finishing prototype, features and the improvements which could happen. In this paper the link margin, fade margin was also discussed with other atmospheric parameters such as rain, turbulence, wind and the need of laser satellite communication.

CHAPTER 2: THEORY OF LASER AND ITS ATTENUATION IN FREE SPACE

2.1.Introduction

"Laser" is one of the most noteworthygift of the last century to the scientific world . Laser is the acronym for "Light Amplification by Stimulated Emission of Radiation". Laser is a device that can amplify light and produce a highly monochromatic, directional, intense and coherent beam. The dimension of a laser device can be from the size of a petite grain to that of a oversized building. The output power can be from 10^{-9} watts to 10^{20} watts with wavelength from the microwave to soft X-ray regions in the electromagnetic spectrum and frequencies from 10^{11} Hz to 10^{17} Hz. The pulse energy of a laser can be as high as 10^{17} joules, having pulse duration as short as 6×10^{-15} seconds.

Lasers are illustrious from other light sources by their coherence. Spatial coherence is characteristically expressed through the output being a narrow beam, which is diffraction-limited. Laser beams can be focused to very tiny spots, achieving a very high irradiance, or they can have very little divergence in order to focus their power at a great distance. Temporal (or longitudinal) coherence implies a polarized wave at a particular frequency, whose phase is correlated over a comparatively great distance (the coherence length) along the beam.[14] A beam fashioned by a thermal or other incoherent light source has an instantaneous amplitude and phase that vary arbitrarily with respect to time and position, thus having a short coherence length.Lasers are characterized according to their wavelength in a vacuum. Most "single wavelength" lasers actually produce radiation in several modes with slightly different wavelengths. Although temporal coherence implies monochromaticity, there are lasers that producea broad spectrum of light or emit different wavelengths of light concurrently.

2.2.History of laser

Laser technology actually initiated with Albert Einstein in the early 1900s, as the technology auxiliary evolved in 1960 when the first laser was constructed at Hughes Research Laboratories. As in the year 1917Albert Einstein lays the fundamentals for laser technology when he predicts the occurrence of "Stimulated Emission," which is essential to the operation of every lasers. After many years later Valentin Fabrikant hypothesized the application of stimulated emission to intensify radiation on the year 1939,whereas Charles Townes, Nikolay Basov, and Alexander Prokhorov expanded the quantum theory of stimulated emission and exhibited the stimulated emission of microwaves. They received Nobel Prize in Physics for this revolutionary work.

In the year 1959 Columbia University graduate student Gordon Gould suggested that stimulated emission can be used to intensify light. He explained an optical resonator which can generate a thin beam of coherent light, and calls it a LASER for "Light Amplification by Stimulated Emission of Radiation". Theodore Maiman constructed the first operational prototype of a laser at Hughes Research Laboratories in Malibu, California 1960. As the created laser uses a synthetic ruby as the active medium and creates a deep red beam of light with a wavelength of 694.3 nm. The first use for the ruby laser was for military range finders and is still used commercially for the drilling holes in diamond since it has a high peak power. The Carbon Dioxide (CO_2) laser is created by Kumar Patel at AT&T Bell Labs. The CO_2 laser was much lower in cost and superior in efficiency than the ruby laser. These aspects had made it the most admired industrial laser type for more than 50 years.[1]

2.3. Basic design of laser

A basic laser structure consists of a gain medium, a method to uplift it, and something to offer a optical feedback.[2] The gain medium is a substance with the properties that let it to intensify the light by the method of stimulated emission. Light of a particular wavelength that goes through the gain medium is amplified (increases in power).

For the gain medium to amplify light, it requires to be supplied with energy in a method called pumping. The energy is characteristically supplied as an electric current or as light at a particular wavelength. Pump light may be offered by a flash lamp or by a further laser. The mainly frequent type of laser uses feedback from an optical cavity—a pair of mirrors on either end of the gain medium. Light bounces back and forth between the mirrors, passing through the gain medium and being amplified each time. In general one of the two mirrors, the output coupler, is partly transparent. A quantity of the light escapes through this mirror, depending on the design of the cavity (whether the mirrors are flat or curved), the light coming out of the laser may broaden out or form a constricted beam. In correlation to electronic oscillators, this device is occasionally called a laser oscillator. Mainly practical lasers have extra elements that influence the properties of the emitted light, such as the polarization, wavelength, and shape of the beam.

Thus it can be presumed that a fundamental laser structure consist of a Gain medium, Laser pumping energy, Output coupler, High reflector, Laser beam. The design of the laser can vary with its diverse system and source as there are several kinds of laser which can be manufactured or built. The **Fig. 2.1** shows the basic laser structure.

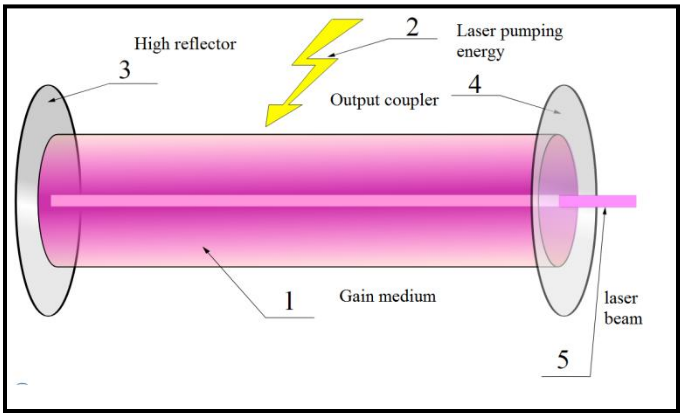


Fig. 2.1: Basic laser structure

2.4.Different types of lasers

Different types of lasers can be classified into solid, liquid, gas and semiconductor lasers. This classification is based on the laser medium that is chosen. The solid laser, a representative of which is the ruby laser, was the first one to be designed. This was directly followed by the gas laser, a representative of which is He-Ne laser. Then came the N d-YAG and glass, argon ion, carbon dioxide, nitrogen, the GaAs junction diode and the dye lasers. Certain other varieties, such as chemical lasers, excimer lasers, gas dynamic lasers, free electron lasers, colour centre lasers, etc., also assumed importance owing to their characteristics in terms of wavelengths, method of excitation, tunability, power levels, cost etc.

2.4.1.Solid State Lasers

A solid state laser was the first laser to be built in this scientific society. Solid state lasers are part of the laser systems involving high-density gain media.Liquid(dye) lasers also fall in this category. Similarly, semiconductor lasers also form part of lasers with high-density gain media. The **Fig. 2.2** shows an example of a solid state laser whereas in this section we will briefly cover the characteristics and basic parameters of the following lasers **:**

(a) Ruby lasers.

(b) Nd-YAG and Nd-Glass lasers.

(c) Chromium LiSAF and ChromiumLiCaf Lasers.

(d) Uranium Cadmium Lasers

(e) Titanium-Saphire lasers.

(f) Alexandrite Lasers.

(g) Colour Centre Lasers

(h) Fiberglass lasers.

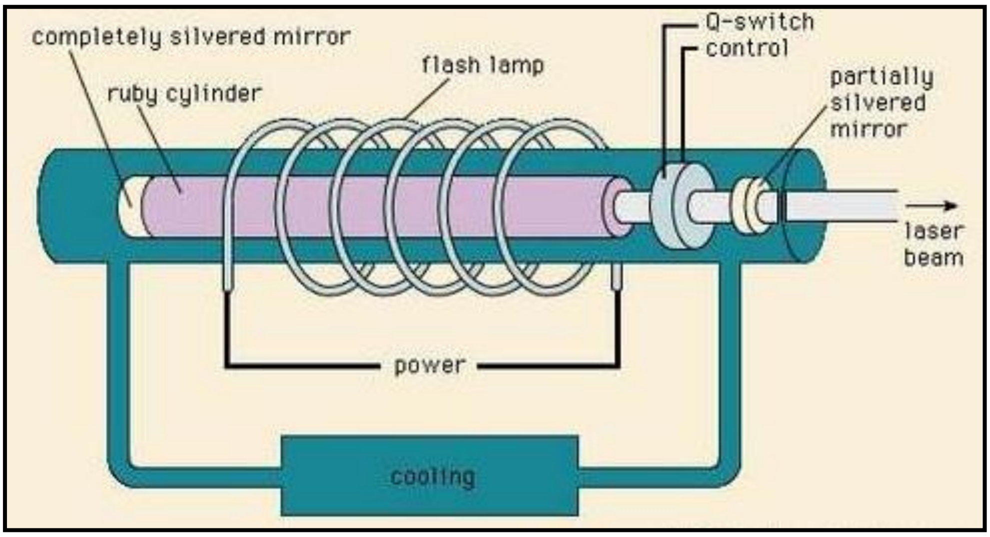


Fig. 2.2: Solid state laser (Ruby Laser)

2.4.2.Liquidlasers

It is hard to build good quality laser crystals with ideal amount which are also costly as well. Crystals are susceptible to defects, blemishes, optical strain, internal damages etc. However, homogeneous liquids have improved optical qualities and they will not collapse, crack or shatter if the output power fluctuates. Liquid lasers are those in which the active medium is formed by the solutions of definite organic dyes dissolved in liquids such as alcohols (methyl and ethyl) or water. These dye lasers belong to the following classes **:**

(a) Polymethine dyes.

(b) Xanthene dyes.

(c) Coumarin dyes and other dyes.

2.4.3.Gas lasers

Gas lasers fall in the group of lasers concerning low-density gain media. The gas media are used in roughly half of the commercial lasers that are presently obtainable. With the advent of solid state lasers which are more compact and with better potential, some of the gas lasers may vanish from the scene in future, still most applications of gaseous lasers will certainly remain for a longtime. Depending upon the characteristics of the active medium, the gas lasers can be categorized into atomic, ionic and molecular lasers. Gas lasers are different from high density lasers. The optical quality is better since there are no optical in homogenities. Some of the other features are line width of the optical transition is smaller, the laser emission is narrower, spectrally, the Q factor of the modes is higher, the monochromaticity is higher, coherence properties are better, a large number of laser transitions have been demonstrated amongst the various gaseous lasers. Such as Helium-Neon laser Argon-ion laser Krypton-ion laser Helium-Cadmium laser Copper vapor Carbon dioxide laser Excimer laser the **Fig. 2.3** shows the basic of gas laser.

Fig. 2.3: Gas Laser

2.4.4. Chemical lasers

In chemical lasers, the energy for pumping is obtained from a chemical reaction. Typical chemical lasers operate on molecular transitions. Majority of chemicalusers operate in near-infrared to middle-infrared portion of the spectrum. The most common chemical lasers are hydrogen chloride (HCL) lasers and hydrogenfluoride (HF) laser. The **Fig. 2.4**shows the basic structure of chemical laser.

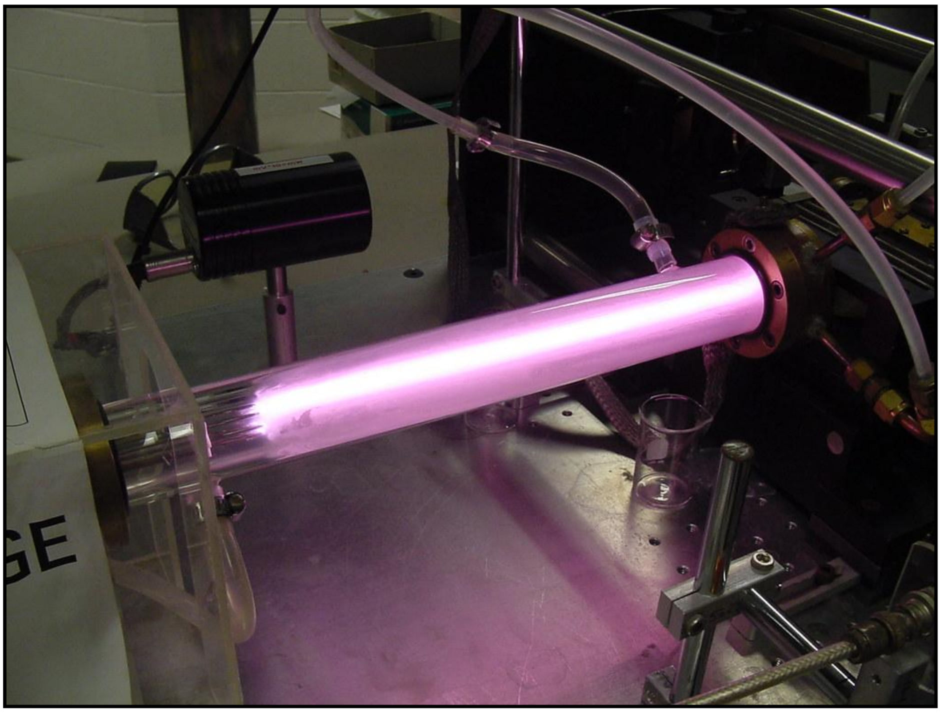


Fig. 2.4: Chemical laser

2.4.5. X-Ray lasers

An X-ray laser is a machine that uses stimulated emission to produce or to amplify electromagnetic radiation in the region near X-ray or extreme ultraviolet section of the spectrum, that is, usually on the order of some of tens of nanometers (nm) wavelength.

Applications of a coherent X-ray radiation consist of coherent diffraction imaging, X-ray microscopy, phase-resolved medical imaging, material surface research, and weaponry. The **Fig. 2.5** shows a X- Ray laser.

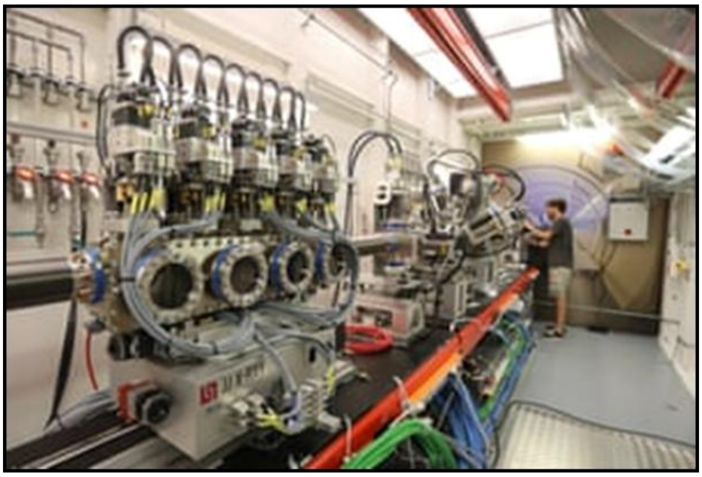


Fig.2.5:X-ray laser

2.4.6. Free electron lasers

The active medium in a free electron laser is a stream of electrons. Through the variation of electron energy, these lasers can be continuously tuned. They offer very high power operation since the media do not get damaged as in the case of solid or liquid lasers.

2.4.7. Semiconductor lasers

Semiconductor lasers are lasers which are based on semiconductor gain media, where optical gain is typically achieved by stimulated emission at an inter-band transition under the situation of a high carrier density in the conduction band. Semiconductors have electrical conductivities lying between those of insulators and conductors. The **Fig 2.6** shows a semiconductor.[3]

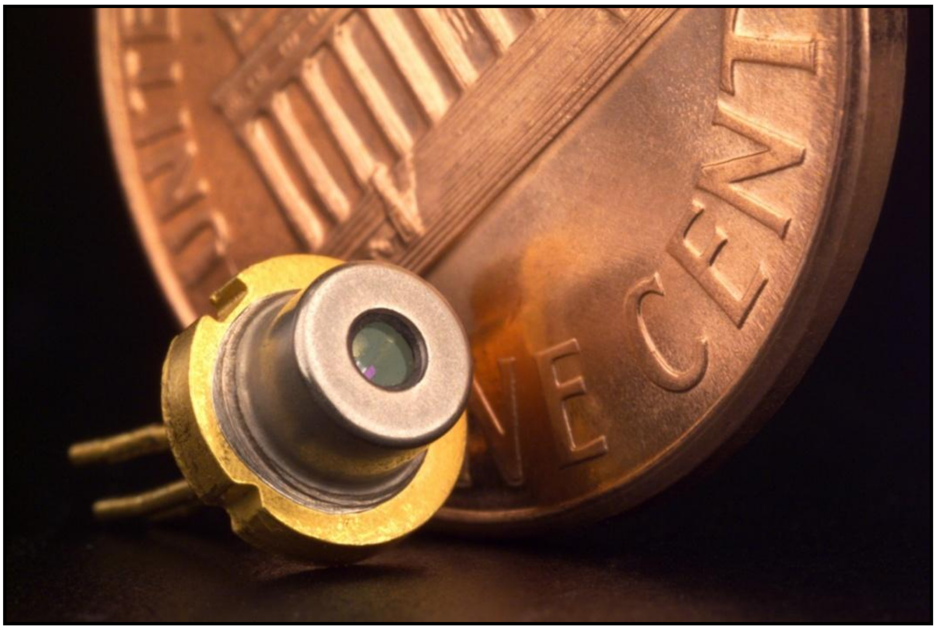


Fig 2.6: Semiconductor Laser

2.5. Absorption of light

The light disappears by the encounter with the particle are called the phenomenon absorption. So, in real meaning, it can be said that light absorption is a process by which light is absorbed and converted into energy [15]. This process is known as photosynthesis in plants. However, light absorption doesn’t occur solely in plants, but in all creatures or inorganic substances. Absorption depends on the electromagnetic frequency of the light and object’s nature of atoms. Absorption of light is therefore directly proportional to the frequency. If they are complementary, light is absorbed. If they are not complementary, then the light passes through the object or gets reflected. These processes usually occur at the same time because light is usually transmitted at various frequencies. (For instance, sunlight also comprises lights of various frequencies; from around 400 to 800 nm). Therefore, most objects selectively absorb, transmit or reflect the light. When light is absorbed heat is generated. So, the selective absorption of light by a particular material occurs because the frequency of the light wave matches the frequency at which electrons in the atoms of that material vibrate.

Absorption depends on the state of an object’s electron. All electrons vibrate at a specific frequency, which is known as their "natural" frequency. When light interacts with an atom of the same frequency, the electrons of the atom become excited and start vibrating. During this vibration, the electrons of the atom interact with neighboring atoms and convert this vibrational energy into thermal energy. Consequently, the light energy is not to be seen again, that is why absorption differs from reflection and transmission and since different atoms and molecules have different natural frequencies of vibration, they selectively absorb different frequencies of visible light.

So, Absorption means reduction of the radiant intensity **I**, and results from many different phenomena. Part of radiated energy transfers into the heat while electromagnetic wave interacts with molecules of the medium.

The absorption is described by the empirical expression called **Beer-Lambert law**, also known as **Beer's law** or the **Beer-Lambert-Bouguer law**

For solids the Beer-Lambert law states that for a parallel beam of monochromatic radiation passing through a homogeneous material the loss of radiant intensity $-\Delta I$ is proportional to the product of pathlength through the material Δx and the initial radiant intensity shown in **Fig.2.7**.

$$-\Delta I = I\tau\Delta x \quad \ldots\ldots\ldots\ldots\ldots(3.1)$$

Where, τ is called the absorption coefficient and represents the relative loss of radiant intensity per unit path length in the material.

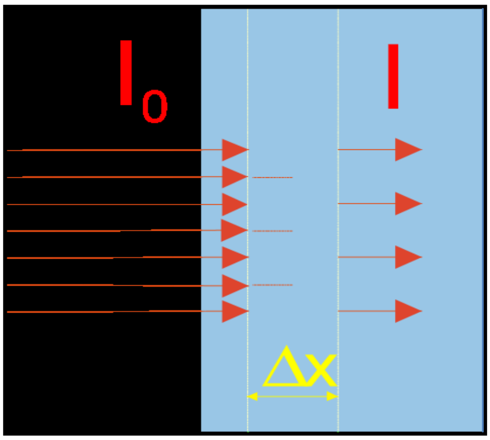


Fig.2.7: Absorption of light

Attenuation of the light by the material Absorption coefficient for the certain material is dependent on the wavelength of light, which results in many interesting and common phenomena (such as coloring). In case of liquid solutions, the coefficient value depends additionally on the solvent and concentration.

Expression (3.1) leads to the more common form of the same statement known as exponential law of absorption.

$$I=I0e-\tau x \text{ .... } (3.2)$$

Which describes the outgoing radiant intensity I after traveling along the path length x in the material. $I0$ expresses the intensity of the light entering the sample. Equation (3.2) expresses the so-called Beer Lambert law for transparent solid material. Light absorption and reflection is shown in **Fig. 2.8.**

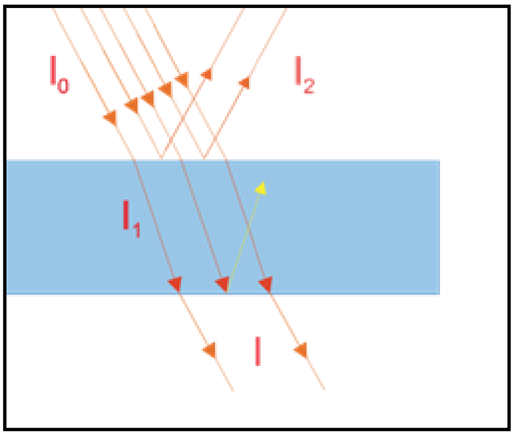


Fig.2.8: Light absorption and reflection

2.6. Scattering of light

When light "hits" a small object (a particle or a molecule), and thereby changes its direction, the thing that happens is called light scattering. If light is being scattered from ordered particles this can cause such phenomena as reflection, refraction or diffraction.

Light scattering can be thought of as the deflection of a ray from a straight path, for example by irregularities in the propagation medium, particles, or in the interface between two media. Deviations from the law of reflection due to irregularities are considered to be random and dense enough (observed for rain) that their individual effects average out, this kind of scattered reflection is commonly referred diffuse reflection. Most objects that one sees are visible due to light scattering from their surfaces. Indeed, this is human's primary mechanism of physical observation. Scattering of light depends on the wavelength or frequency of the light being scattered. Since visible light has wavelength on the order of a micrometer, objects much smaller than this cannot be seen, even with the aid of a microscope. Colloidal particles as small as 1 micrometer, have been observed directly in aqueous suspension.

The physical cause is the same as the scattering effect in rain- light hits moisture droplets and scatters. As droplet size decreases, however, both the type and amount of scattering change. Smaller droplets cause more scatter and especially more backscatter. Fog is produced by suspension of very fine droplets in the air, so the amount of scattering is even larger and there is more loss of contrast and more backscatter from headlights. This is the reason that a person should not use high beam in fog.

Models of light scattering can be divided into three domains based on a dimensionless size parameter, α which is defined as equation 3.3

$$\alpha = \Pi d / \lambda \ \ldots\ldots\ldots\ldots\ldots (3.3)$$

where πD_p is the circumference of a particle and λ is the wavelength of incident radiation. Based on the value of α, scattering can be classified as

$\alpha \ll 1$: Rayleigh scattering (small particle compared to wavelength of light);

$\alpha \approx 1$: Mie scattering (particle about the same size as wavelength of light, valid only for spheres);

$\alpha \gg 1$: geometric scattering (particle much larger than wavelength of light).

As the object is scattering in fog. So, the discussion will be about Rayleigh scattering and Mie scattering [16].

2.6.1.Rayleigh scattering

Light an electromagnetic wave is characterized by electric and magnetic field vectors. For simplicity, it is considered the case of a plane wave, linear polarized incident on a small spherical particle. The wavelength of light in visible range is about 0.5um. For particle much smaller than the wavelength the local electric field produced by the wave is approximately uniform at any instant. This applied electric field induces a dipole in the particle. As the electric field oscillates, the induced dipole oscillates and according to classical theory, dipole radiates in all the direction. This type of scattering is called Rayleigh scattering.

The dipole moment" P "induced in the particle is proportional to the instantaneous electric field vector as equation 3.4

$$P = \alpha E \qquad (3.4)$$

This expression defines polarization. α, which has the dimension of volume and which is a scalar for all isotropic spherical particle. From the energy of electric field produced by the oscillating dipole, an expression can be driven for the intensity of scattered radiation as equation 3.5

$$I=(1+\cos^2\theta)k^4\alpha^2 2R^2/I_0 \qquad (3.5)$$

R= distance to the particle; θ= scattering angle; α= scalar (value depends on refractive index)

K= wave number = $2\pi/\lambda$. $I0$=initial intensity of the light.

The scattering is symmetrical with respect to direction of incident beam with equal maxima and minima in forward and backward direction and minimum at right angle.

Intensity of the scattered light varies inversely with the fourth power of the wavelength, blue light (short wavelength) scattered preferentially to red [17].

2.6.2. Mie scattering

If the scatters are large compared to the wavelength of light then geometric optics provide a good approximation. However, in most atmospheric situations aerosols are neither large nor small enough to be treated simply.

The size parameter, $\alpha = 2\pi a/\lambda$, is between 1 and 20.

This problem was first solved by Gustav Mie (1908) by determining the wave vector in spherical coordinates for e-m waves, specified by 'Maxwell's equations'. In general particles absorb as well as scatter and Mie gave solutions for the absorption, scattering and extinction cross sections as a function of the scattering angle.

Mie scattering intensity for large particles is proportional to the square of the particle diameter. After scattering from particle, the ray of light directed towards the way the incident ray of light was coming. This type of scattering is observed mainly for dust particles. But the atmosphere consists of lots of small water droplet during fog which causes scattering of this type less than Rayleigh scattering. Rayleigh and Mie scattering are shown in **Fig. 2.9.**

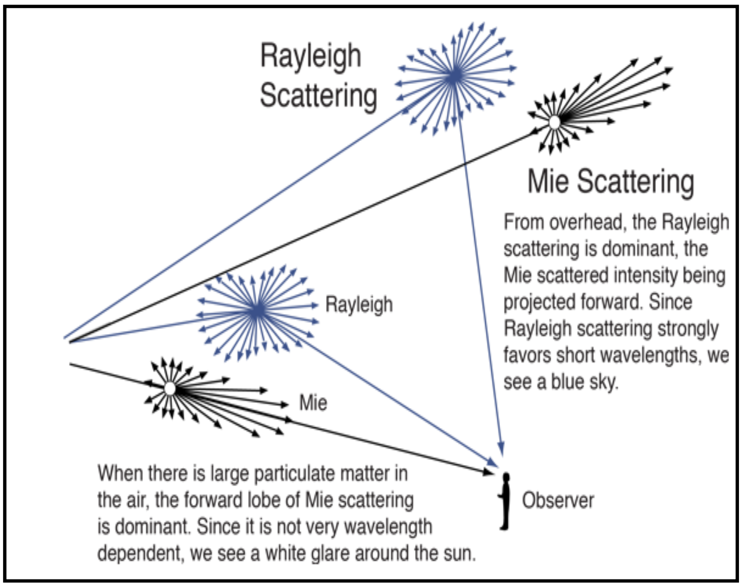


Fig.2.9: Rayleigh and Mie scattering

The amount of contrast lost depends on the distance of object and the coefficient of scatter of light in that medium. This is turn dependent size and density of moisture droplets suspended in the atmosphere. These values vary with location of the fog, as droplets in urban areas are usually smaller due to dust particles in the air.

When air particle become very small, the situation is more complicated because not all wavelength is affected equally. Air molecules, for example, scatter short wavelength (blue) more [17].

2.6.3. Geometric scattering

This is a phenomenon when the photons particles collide with the structure of the particle in the free space, but as the particles which are suspended in the air are different than that of the likes of the above mentioned scattering, and then this type of scattering will be different.

The size of the particle which is suspended in the air is larger than the wavelength of visible light which is around 400-700nm then that type of scattering is called geometric scattering. As the size of the particles are more than the wavelength of the light, the pattern of the scattering changes drastically as the scattering becomes directional in a non-predictable way. The type of scattering becomes lob like structure with mostly scattering in forward direction. As in Rayleigh's scattering the scattering is uniform in all direction as the particles were extremely small in compared to the wavelength of the light but in these type the pattern is very directional which helps to understand that in case of the rain which falls under this type of scattering. The scattering nature is very volatile as it creates an inference with the size of the water droplets and the photons are scattered through the rain drop in different directions but the majority of the scattering is facade. **Fig 2.10** shows the scattering pattern of geometrical scattering.

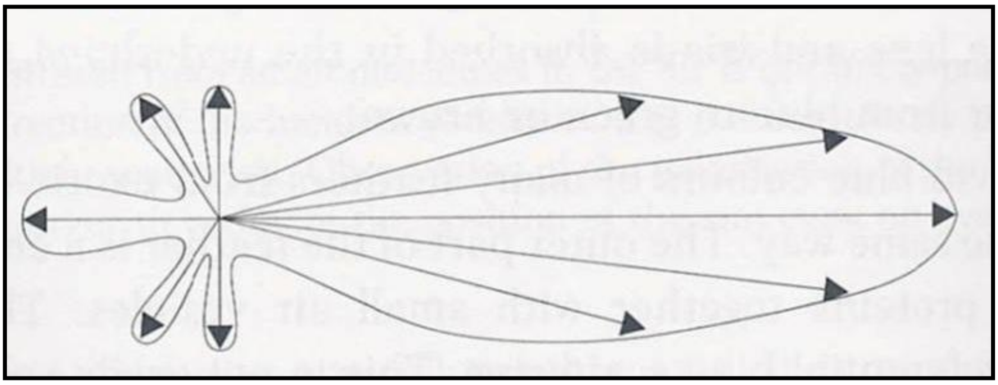


Fig 2.10: Geometric scattering

Chapter 3: COMMUNICATION SYSTEM, FSO AND IT'S ATTENUATION

3.1.Basic communication processes

Communication is basically the sending and receiving of information between at least two people. The message may be verbal or non-verbal, but to be effective, the message sent must be in a language or code that the receiver will recognize.The **Fig. 3.1** shows the basic communication system.

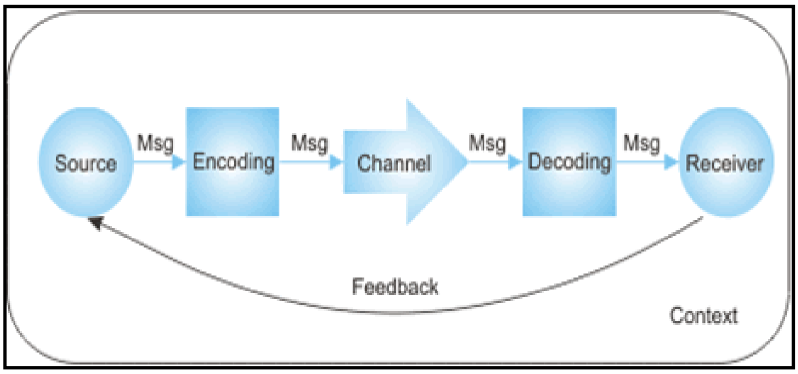


Fig. 3.1: Basic communication system

3.1.2. Successful and unsuccessful communication

Communication problems occur when sender and receiver do not share the same code or understanding of the language used

The information can be transferred through the means of various channels as -:

a) Verbal channels: It involves face-to-face meetings, telephone and video-conferencing.
b) Non-verbal channels: It involves sign languages, body language, gestures, and facial expressions.
c) Written channels: It involves letters, emails, memos and reports, signs and symbols.

Different communication channels have different strengths and weaknesses but the most crucial factor in any mode of communication is that the receiver can access the message correctly through that channel.

3.1.3. Two-way communication process

In an effective two-way communication, the sender (or the source) encodes the message into a form which can be perceived by the receiver correctly and thereafter relays the message via an appropriate channel.

The receiver is then able to access the message and then decode the same for further processing.

After the receiver recognises the message it becomes the sender by providing a feedbackresponse and the process continues until the communication concludes.

At any time in the process, a lack of response or an inappropriate response would alert the sender to a problem with the communication. The sender would then encode the message differently, or use a different channel to ensure that the communication is received and understood correctly.

3.2. Wired communication system

Wired communicationis typically the transmission of data over a wire-based communication medium.

3.2.1.Types ofwired communications

a) Twisted pair: Twisted pair consists of a pair of wires that are twisted together. The twisting reduces noise on the wires by reducing the amount of electromagnetic interference from the environment and between transmitter and receiver.

b) Coaxial Cable: Coaxial cables consist of a cylindrical wire running down the middle of an insulating sheath. Surrounding the insulating sheath is a conductive sheath, acting simultaneously as a shield and a return path for the signal. Coaxial cables are highly resistant to noise due to the shielding which keeps most of the electromagnetic energy inside the surrounding conductive sheath.

c) Ethernet:A system for connecting a number of computer systems to form a local area network, with protocols to control the passing of information and to avoid simultaneous transmission by two or more systems.

d) Fiber Optic Cable: A fiber optic cable consists of a very long thin fiber of glass using which light pulses can be sent. The data rates supported by fiber optic networks are incredibly fast. The light pulses travel through striking the glass fibre surface and undergoing total internal reflection.

3.2.2. Advantages and limitations of wired communication system

A wired communication system has -

Advantages

a) A higher immunity to outside interference and noise.
b) The allocation of frequencies is determined by the owner of the wire, not by regulatory authorities improving data security.

Limitations

a) The Wired communication system has a limitation to its portability due to always having a need to be connected to a power outlet.
b) These systems have a specific space requirement and have some vulnerability to wear and tear.

3.3. Wireless communication system

Wireless communications systems arecommunications systems that do not use wires for the motive of propagating information. This category could include such anachronisms as smoke signalling and semaphores. The **Fig. 3.2** shows an example of wireless communication.

Fig 3.2 : Wireless communication

3.3.1.Types of wireless communication systems

Wireless communication has various forms, technology and delivery methods including :-

a) Satellite communication

b) Mobile communication

c) Wireless network communication

d) Infrared communication

e) Bluetooth communication

3.3.2. Advantages and limitations of wireless communication system

A wireless communication system has advantages and limitations are given below:

Advantages

a) These are cheaper to deploy, especially if the network covers a large area with no current coverage. There is no need to connect wires to all the points that need coverage.

b) Usually easier to deploy, but that depends on the size of the network. A point to point connection is easier to wire.

c) Users of the network are more mobile; they are not tied down to any particular spot.

Limitations

a) Data sharing speed can be slow and can be even slower depending on the distance of the receiver from the transmitter.

b) Wireless modes of communications are unsecure and information can be leaked while data transfer is in process.

3.4. Optical wireless communication

Optical wireless communications (OWC) is a form of optical communication system in which unguided visible, infrared (IR) and ultraviolet (UV) light are used to carry information signal.

3.4.1.Visible Light Communication (VLC)

Visible light communication (VLC) is a type of communication process which uses visible light between 400 and 800 THz (780–375 nm), by simply defining any form of information that can be sent using a light signal which is visible to humans could be defined as VLC. The prospect of sending data usefully in this manner has given a significant rise of the wide spread LED light bulbs as a transmitter device .As switching bulbs at very high speeds is not possible with older light bulb technologies such as fluorescent and incandescent lamps but LED being a semiconductor has been used in this field quite healthy. The fast acceptance of LED light bulbs has created a colossal opportunity for VLC.

3.4.2Free space optical (FSO) communication

Free space optical (FSO) communication is comparable to VLC but is not constrained to visible light, so ultraviolet (UV) and infrared (IR) also comes under the FSO category. Furthermore, there is no illumination requirement for FSO and so this tends to be used in narrow beams of focussed light for applications such as communication links between buildings. FSO often uses laser diodes rather than LEDs for the transmission.

Free space optical communication is a line of sight based communication which requires information carrying light to travel across the atmosphere between the transmitting and receiving nodes. The earliest form of light based communication through free space can be traced back to 1880 when Alexander Graham Bell, demonstrated the working of a photo phone, which could carry voice signals modulated on sun's radiation through a distance of 200 meters.However at that time, the equipment and methodology involved was very nascent, thus this experiment was not any major success. However, in late 1970s with advent of advanced optical devices like high powered tuneable lasers and detectors, FSO communication has witnessed massive up gradation along with huge interest of researchers around the globe. The first commercial FSO link was used in Japan by Nippon Electronic Company in 1970s to handle air traffic.

3.4.3.FSO in modern times

Till date FSO technology has been used to fulfil the requirements of military for faster and discrete communications. Space research agencies like NASA has also been vigorously working on light based deep space communication which will be used for various space expeditions like that of mars and lunar probe missions.

However in the current situation where the severe bandwidth crunch and the demand for data rates at all-time high, FSO systems can be an excellent alternative to established RF system for data and voice communication. Since FSO links operate in licence free band, hence these systems can be very conveniently used for short range communication, particularly as last mile solution to bridge the bandwidth gap between the end user and the network hub. Despite atmospheric effects being biggest challenge in the way of FSO implementation, the hybrid version of FSO and RF has seen great experimental success and will surely be the future practical solution to migrate from current bandwidth starved RF systems to optical systems along with maintaining excellent uptime.

FSO could not really pick up commercially because our need for reliable communication networks was adequately satisfied by the existing radio and microwave infrastructure. Secondly, FSO being light based communication through free space was always an unreliable communication technique, especially under the conditions of fog, rain, snow and atmospheric turbulence effects which leads to scattering and loss of optical signal. These two were major reasons that lead to slow penetration of FSO links into the commercial domain.

3.4.4. Advantages of FSO

a) Spectrum licensing**:** The biggest concern today for radio systems is interference with existing commercial and military systems. Currently, the frequencies above 300 GHz (less than 1 mm in wavelength) have not been regulated by FCC. Free Space Optics (FSO) systems use frequencies above 30 THz so they do not require spectrum licensing.

b) Bandwidth and data rates**:** Currently, commercially available FSO products provide data rates of 2.5 Gbps. Demonstration systems report data rates as high as 160 Gbps. Bandwidth is closely related to data rate. High data rates require a lot of spectrum, which is why FSO technology is becoming more popular.

c) Data security**:** In order to detect a laser transmission, a detector or receiver must be located within the laser beam cone, between the transmitters or behind the receiver to intercept uncollected part of the beam, but this is highly unlikely because microwave transmitters have a divergence angle of a few degrees where FSO systems have a few milli radians (1 mrad=0.0573 degrees). The interruption of the laser signal would result a sudden drop in received power at which point the manager software built in the systems may notice and cease the transmission, which may not be sufficient to extract information.

3.4.5.Limitations of FSO

a) **Atmospheric effects**

Since FSO systems involves transmission of optically modulated signal through atmosphere as medium, hence the optical radiation is subjected to various atmospheric phenomena's like rain, wind, snow and fog etc. These effects along with atmospheric turbulence can make the communication link very inconsistent. Since atmosphere is composed of various gases, aerosol particles and water droplets, the optical signal undergoes various degrees of scattering and degradation as it transverses along the link range.

b) **Line of sight**

Second challenge in FSO links is line of sigh communication. FSO links require highly directional narrow laser beams to communicate and there must not be any physical obstruction between the communicating nodes else the data may be either partially or completely lost, which is defiantly highly undesirable.

c) **Directional precision**

Free Space Optics (FSO) systems use narrow laser beams. Typically, commercially available FSO systems have a beam divergence from 0.1 degrees to 0.3 degrees, which is very small compared to microwave systems. For a beam divergence of 0.1 degrees, the diameter of the laser beam is 1.74 meters at a distance of 1 km.

d) **Laser safety**

The safety of FSO technology is often a concern, since it uses lasers for transmission. LASER is an acronym that stands for Light Amplification by Stimulated Emission of Radiation. The laser produces an intense, highly directional beam of light. The unprotected human eye is extremely sensitive to laser radiation and can be permanently damaged from direct or reflected beams.

3.4.6.Types of attenuation in FSO

a) Link Margin

Before the evaluation of the attenuations that affect the linkwe need to know the link margin which is the threshold forlink performance. Link margin or fade margin is thepercentage of time that the link is operating satisfactorily andwhen the link margin is not exceeded is known as linkavailability.

b) Geometrical Attenuation

Knowing geometrical attenuation then it is possible toevaluate received power level and link margin in order toevaluate the performance of FSO links. Geometricalattenuation is a fixed value for a specific FSO system since itdoes not vary with time. Geometrical attenuation occurredwhen the light beam is diverged as it moves throughout itspropagation path. As a result not the entire light beam hits thereceiver.

c) Scintillation

Scintillation is a random, rapid fluctuation in light intensityat the receiver. It is occurs during a hot, sunny day, when thesun heats up the ground and the surrounding air. It will makethe convection current rising up and cause air pocket to moveabout in a turbulent manner.Some air pockets heat up morethan others and it behave like lenses, focusing and defocusingthe laser beam as it passes through the atmosphere.

d) Molecular absorption

It occurs when the beam particles interact with themolecules present in the atmosphere such as N2, O2, H2, H2, CO2, O3, etc. If theincident wave corresponds with one of the resonant frequency of the present gases,molecular absorption takes place, resulting in the so-called blocking windows of thetypical atmospheric absorption spectra In the infrared region themain molecular absorbers are water vapor, carbon dioxide and ozone, being themost affecting absorber water vapor for the near-infrared spectrum (up to 3 μm).

e) Aerosol absorption

Aerosols are fine liquid or solid particles in suspension inthe atmosphere of size ranging between 10^{-2} and 10^{2} μm. Their origin is diverseand depends on the geographic location, such as droplets of water (drizzle, fog,foam) along with salt crystals in maritime regions; or human-made aerosols inurban areas, such as sulfates from coal power plants or black and organic carbonfrom motor vehicle emissions. The aerosol concentration also depends on the timeof the day and meteorological conditions and influence atmospheric transmissiondifferently depending on their concentration, size and chemistry. This gives rise tothe term visibility, which defines the line of sight of the optical link.

f) Rain

Rain attenuation is also known as "specific attenuation". Rain attenuation greatly relies on different models of raindrop-size approximation. The specific attenuation of optical wireless link for rain rate R is given by in equation (1)

$$\gamma_{rain} = a \cdot R^{b} \quad (1)$$

Where a and b are power law parameters which dependson frequency, rain temperature and rain drop size. Thespecific attenuation of rain is given by the relation

$$\alpha_{rain} = 2.9 / V \quad (2)$$

Where, V is the visibility range in km.

Chapter 4: INSTRUMENTS USED IN EXPERIMENTAL WORK

4.1. Voltage-controlled oscillator (VCO)

The device used in this thesis is voltage-controlled oscillator (VCO) is an electronic oscillator whose oscillation frequency is controlled by a voltage input. The applied input voltage determines the instantaneous oscillation frequency. Consequently, a VCO can be used for frequency modulation (FM) or phase modulation (PM) by applying a modulating signal to the control input. A VCO is also an integral part of a phase-locked loop.

In this experiment, a VCO is used to control the frequency of the modulated signal which is used to transmit via five DPSS lasers of different wavelengths. **Fig. 4.1** shows the VCO used in this research work .

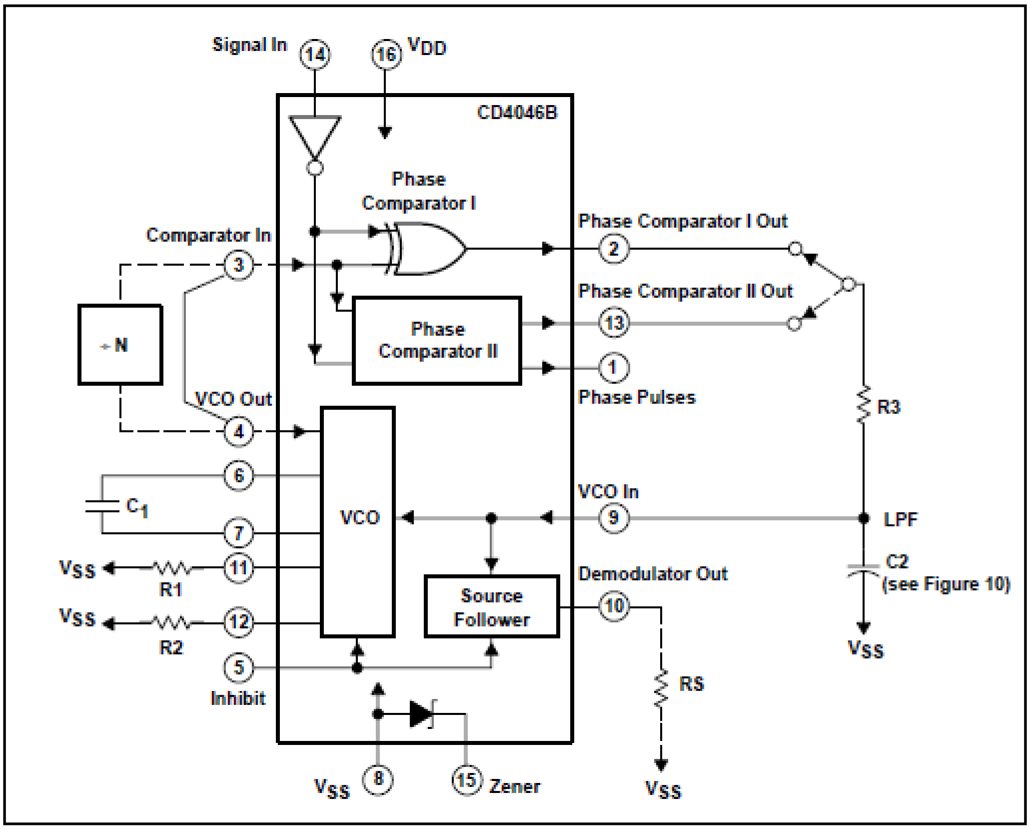


Fig 4.1 :VCO used in this experiments

4.2.Photodetector

A photo detector is a PN-junction diode that consumes light energy to produce electric current. Sometimes it is also called as photo-detector, a light detector, and photo-sensor. These diodes are particularly designed to work in reverse bias condition, it means that the P-side of the photo detector is associated with the negative terminal of the battery and n-side is connected to the positive terminal of the battery. This diode is very complex to light so when light falls on the diode it easily changes light into electric current. The solar cell is also branded as large area photo detector because it converts solar energy into electric energy. Though, solar cell works only in bright light.

A photo detector is one type of light detector, used to convert the light into current or voltage based on the mode of operation of the device. It comprises of optical filters, built-in lenses and also surface areas. These diodes have a slow response time when the surface area of the photo detector increases. Photo detectors are alike to regular semiconductor diodes, but that they may be either visible to let light reach the delicate part of the device. Several diodes intended for use exactly as a photo detector will also use a PIN junction somewhat than the usual PN junction. The basic structure of a photo detector is shown in **Fig. 4.2**.

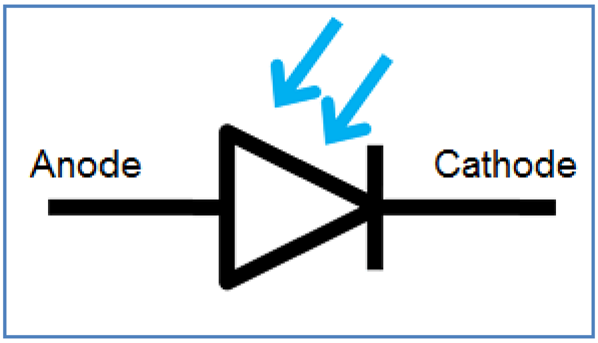


Fig. 4.2: Basic structure of Photo detector

4.3.Diode pumped solid state lasers

Within the past few years, a great interest has been observed in the use of semiconductor diode laser pumped solid-state lasers (DPSSLs) based on rare-earth ion-doped transparent solids like neodymium-doped yttrium aluminum garnet (Nd:YAG). Diode lasers are employed for pumping doped glass or crystalline gain materials in solid-state lasers instead of flash lamps due to their higher efficiency and long lifetime. Owing to high energy along with high quality beam characteristics, such solid-state lasers have extensive list of applications in industrial, medical and defense fields. In diode pumped solid state lasers design parameters that highly influence the laser system performance like energy transfer efficiency, beam overlap efficiency and output coupling reflectivity directly affecting the output power and the input threshold power solid-state lasers. In combination with different spectroscopic techniques, diode-pumped solid state lasers(DPSSLs) have extensive applications in remote sensing, information storage, material processing, range finding, etc as well. For the empowerment of existing and new applications, along-standing and ongoing effort is continued for investigating novel gain hosts . As DPSS laser are more compact and efficient than other lasers thus, high power DPSSLs have replaced ion lasers and flash lamp-pumped lasers in many fields of scientific experiments, the lasers are developed in a wide range of wavelength. **Fig. 4.3** shows quantity of lasers used in the experiments.

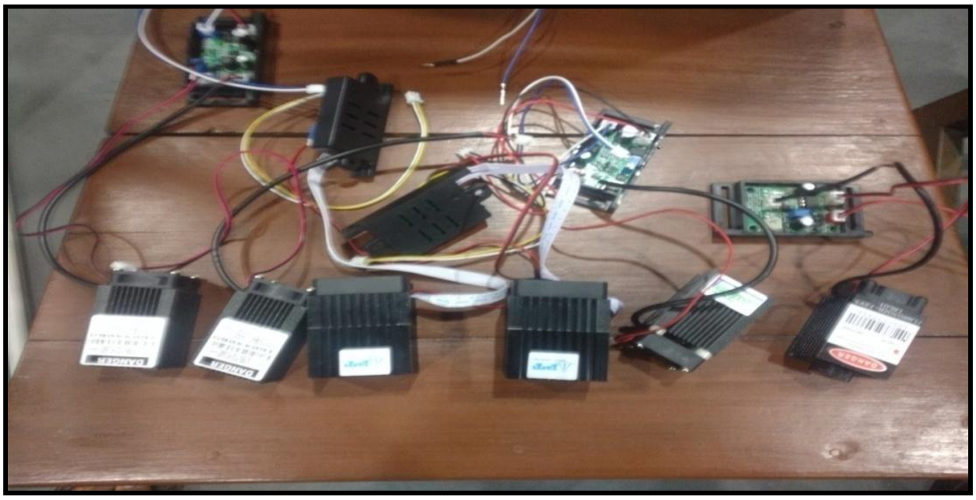


Fig. 4.3: DPSS lasers used experimental work

4.4. Infrared viewer

In this thesis multiple experiments are performed by using Infrared lasers. As infrared lasers emit laser light which are not visible to human eyes. Thus it can be very difficult for participants to follow the beam path or to check a beam position without any visual aid. Therefore, one often uses infrared viewers (IR viewers), i.e., devices which effectively make infrared light visible. One can look into the ocular lens (eyepiece) of such a viewer and see an image which is created from infrared light entering the device through the objective on the opposite side.In the**Fig 4.4:** Infrared viewer used in the following experiment.

The basic operation principle of an infrared viewer is as follows:

a) Infrared light from some source, entering the objective, is imaged onto some image converter. That device has a photocathode (a photosensitive area) inside an evacuated tube where photoelectrons can be generated by incident infrared radiation.

b) The generated photoelectrons are accelerated by a strong electric field (created by applying a high voltage of e.g. several kilovolts) and then hit a phosphor on the opposite side of the tube. There, the electrons cause the phosphor to glow; depending on the type of phosphor, the color of the emitted light may e.g. be green. (The emitted light color is independent of the wavelength of the radiation hitting the photocathode.) As electrons generated on different locations on the photocathode are sent to different locations on the phosphor, a visible image is created there.

c) The visible light can then get through the ocular into an eye of the user, so that a visible image can be generated on the retina.

Fig. 4.4: Infrared viewer used in experimental work

4.5.Laser power meter

Laser Power Meters measure the energy output of laser beams for testing or laser system applications. Laser Power Meters use detection sensors to determine the intensity of a laser beams energy output. Laser Power Meters are designed to analyze lasers within a particular range of wavelengths or intensities. Laser Power Meters are available in a wide selection of wavelength ranges for customization over a large number of laser measurement needs.

In the following experiments a particular high sensitive laser power is used, in the receiver end of the laser to capture the exact power of the lasers.The **Fig 4.5** shows the diagram of laser power meter used in the following experiments.

Fig. 4.5: laser power used in experimental work

*Chapter 5:*ARTIFICIAL RAIN SIMULATION -I

5.1. Introduction

Rain is one of the most majestic and beautiful creations of earth yet it is one of the most dangerous natural calamity that damages life and resource. The rain has been a part of human civilization from the beginning and thus plays a very important role nowadays. The study of rain in very much needed to actually avoid the natural disaster, and prevent further catastrophe as much as possible. The control over rain has proven to be very difficult, as the scientific society has failed miserable for past many decades. This is one of the reasons why this experiment is done, which is experimented in the best to worst circumstances in the real life and real time situation.

As we have known for the fact that rain can be controlled, thus an artificial rain simulation setup was proposed. This setup is very different and the fact that it is built for the sole purpose for simulation, with the notion for studying the attenuation characteristic of different laser by introducing the laser beam through the rain. As it is observed that free space communication in many ways hampered by the likes of natural phenomenon like rain, dust, snow, smoke, and other aerosols. In this particular matter the divisive element of rain is been formulated and artificially created to actually have a more clear depth and insight on the attenuation of signal carrying laser beam.Rain is an important factor of attenuation and distortion signals in receiver systems. Heavy rain is expected to be the limiting factor for FSO link availability, which is the main reason to showcase the through study of different densities of rainfall upon the information carrying laser beam.

5.2.Experimental plan and setup

The object of the communication system is to transfer data or information from a transmitter at one point to a receiver at another through the intervening atmospheric channel with an acceptance error rate while providinghighreliability. The transmitterconsist basically of a laser, which is 808nm which is infrared with its laser module and laser driver, the laser driver draws 12 V and the module around 5 V. The modulator converts bits of information into electrical signal and modulates the laser to generate an optical signal, in this particular experimental setup, 10 kilo hertz is formulated. The optical signal propagates through the atmospheric channel and is collected by the receiver to recover the data. On the receiver side, it consists of a detector and a decoder to get the signal back. In this experiment,the decoder used is BPW34 which is a semiconductor photodiode as the detector converts the optical signal back to electrical signal.

Thus by this process the prolonged experiment will be performed by transmitting a preset specified frequency created by using VCO oscillator and then with the help of the modulator and laser module, which will be beamed via 808nm diode laser. The modulated beam will be passed through rain, which is artificially simulated, and then it will be received at the other side, which is the receiver end, with the photodiode placed to demodulate the frequency carried laser beam. Then that signal would be formulated and analyzed to have a thorough in-depth knowledge on the attenuation of the laser beam with the loss of data sent.

The experiment was conducted indoors with very low artificial light effecting the whole setup during the whole experiment as the distance between the receiver and the transmitter was 100 meters, and was arranged methodically with laser transmitter and receiver aligned in a straight line. The main artificial rain simulation is created with the help of a rectangular metal hollow box like shape which was custom made for this experimental purpose only, the measurement of the instrument are as follows, height was 5.5 feet and the breath was 0.19 feet while the width of the instrument was 0.05 feet.

The instrument acted as a perforated metal rectangle box with the holes being 1mm in diameter as the sole purpose of the device made is to have a more uniform shower like system, with the water falling over the desired link established. As the instrument has a opening diameter of 1.5 cm where it is connected to a hydraulic pump of 0.5 horsepower (Hp). The hydraulic pump inlet in then submerged in the 500 liters water tank, where the desired water is kept. The water used in the experiment is freshwater with no to little amount of salt and impurities added.The whole process starts with the water tank being filled with freshwater with the help of a local water source and then the tank is being fully filled, which allows the experiment to move into its next stage. Then the 0.5 Hp pump was used to channelize the water through the pipe to the instrument with a heavy force, as the significant large amount of water is being transferred through the pump to the instrument. This process is very significant in this particular way as there is a regulator node within the hydraulic pump which is used to control the flow of water towards the instrument . As it helps to define and correlate the amount of intake water inside the instrument which is used as an artificial rain simulator. By this process the control of the rain rate was achieved, which helped to have a more clearer and in-depth analysis of the attenuation of the power of the laser beam and the frequency modulated into the laser beam. The power meter mentioned above is being thoroughly used at the receiver end of the aligned laser link. After that the photodiode is being used to acquire the modulated signal and with the help of an oscilloscope the received frequency is observed. On the receiver side of the system the photodiode and the oscilloscope require 5 volts and 12 volts respectively, which is then provided by the variable DC power supply. In this particular experiment another set of oscilloscope and variable DC power supply was required on the transmitter side of the setup where it provided 5 volts to the module of the laser system and 12 volts to the main laser device . The oscilloscope was being used to determine the preset frequency of the modulated laser signal before the attenuation through the artificial rain so as to give a platform by which the comparison can be made by how much the attenuation is conceived.**Fig. 5.1**shows the diagram of Experimental Setup of Rain at Transmitter Side & Receiver Side.

Fig 5.1: Experimental setup of rain at transmitter side and receiver side

5.3.Experimental results

As mentioned earlier in the above, the experiment is being conducted by varying the rain-rate using the regulator node in the hydraulic pump in order to have a profound knowledge of the nature of the attenuation caused by the rain to the modulated frequency carrying the signal. Thus the experiment is done in primarily three parts, excluding the data collected without rain, which is light mode (light rain), medium mode(medium rain) and heavy mode(heavy rain) which is shown in **table 5.1.**

Table 5.1: Experimental results of rain simulation with different parameters

Sl. No	**Rain Rate (mm/min)**	**Rain Exposed Length(ft.)**	**Frequency(Transmitter Side)(KHz)**	**Frequency(Receiver Side)(KHz)**	**Laser Power (Transmitter Side)mW**	**Laser Power (Receiver Side)mW**
1.	Without Rain	5.5	9.78	9.78	65	57
2.	62 (light mode)	5.5	9.78	8.27	65	47
3.	72 (medium mode)	5.5	9.78	6.80	65	31
4.	90 (heavy mode)	5.5	9.78	5.80	65	18

5.3.1.Frequency variation in different rainy conditions using digital oscilloscope

It is been observed that with the change in the rain rate in the experiment there is a significant change of the frequency in the receiver end which is fairly related to the amount of rain falling on the laser link by the rain artificially generated. There is also the decline in the power as well, as the amount of loss is directly proportional to the increase of the rain rate, which is also similar as an account of the case of frequency.

5.3.2.Frequency profile at transmitter and receiver end

a) Frequency profile at transmitter end

As mentioned earlier, the experiment is been conducted to find out the in-depth analysis of the attenuation of the frequency and power of laser modulated beam with a preset frequency passed through the artificially simulated rain, thus to study the loss of the frequency of the diode laser, the frequency from the transmitted side has been taken as a point of source which plays a vital role in comparison with the other frequencies which is collected at the receiver side. In transmitter side, it show that 9.78 KHz transmitted in **Fig 5.2.**

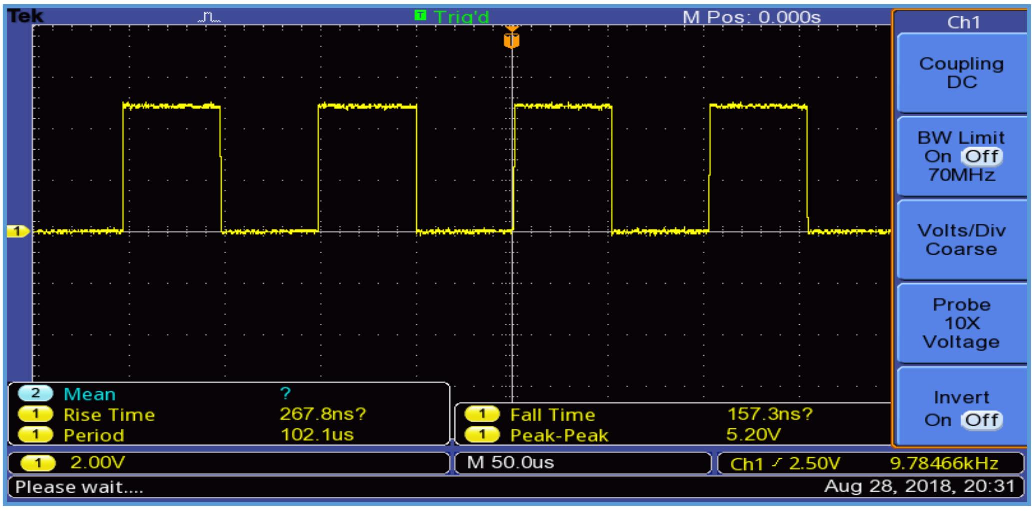


Fig 5.2: Frequency Profile at Transmitter End

b) Receiver side frequency(without rain)

In receiver side, the signal of 9.78 KHz was received which is shown in **Fig. 5.3.**

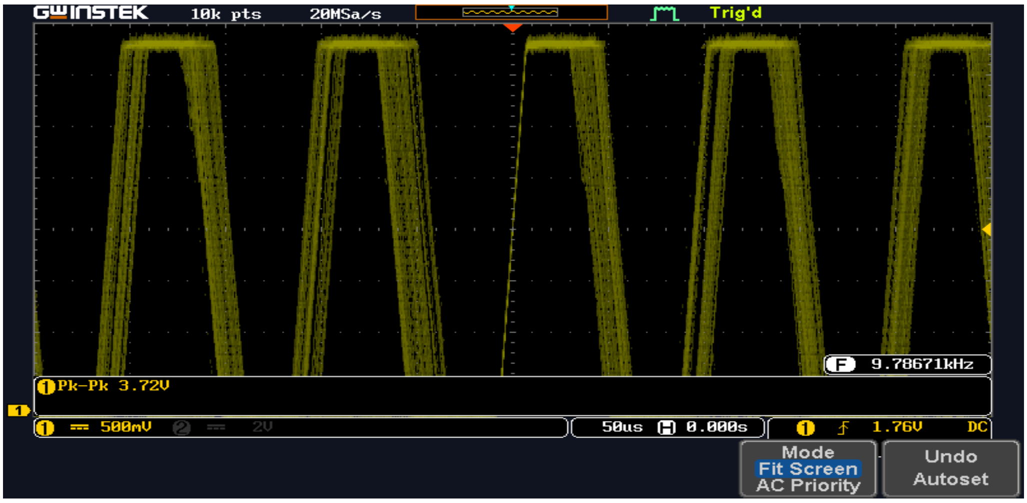


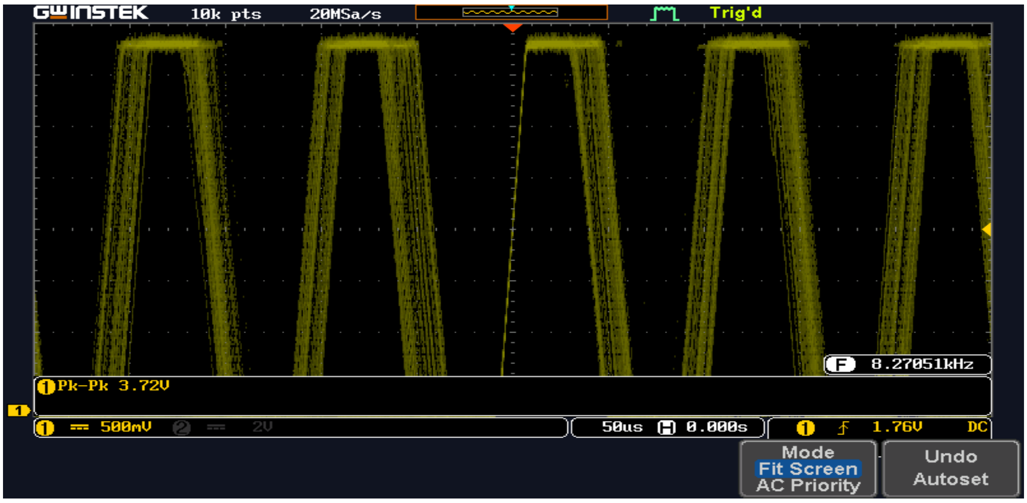
Fig 5.3: Receiver Side frequency without Rain

5.3.3.Receiver side frequency (light mode)

In this case the experiment is been conducted with help of mode regulator of the hydraulic pump where the flow of water is been controlled as in result the water which is entered to the instrument via pipe is less thus the rain rate is significantly less. The rain rate was recorded is 62mm/min.

Fig. 5.4 shows data at the receiver side, where 9.78 KHz frequency becomes 8.27 KHz frequency in this situation.

(a)



(b)

Fig 5.4: (a) Rain mode: light and **(b)** Receiver side frequency with rain rate 62mm/min

5.3.4. Receiver side frequency (medium mode)

The amount of water is entering the instrument is further changed as the node is released a bit where resulting in the increase of the amount of water in the instrument, which increase the rain rate of the system, thus the rain rate increase dto the point which was recorded to have rain rate 72mm/min.

In receiver side, the 9.78 KHz frequency has been degraded to 6.80 KHz frequency in this situation. That has been shown in **Fig 5.5**.

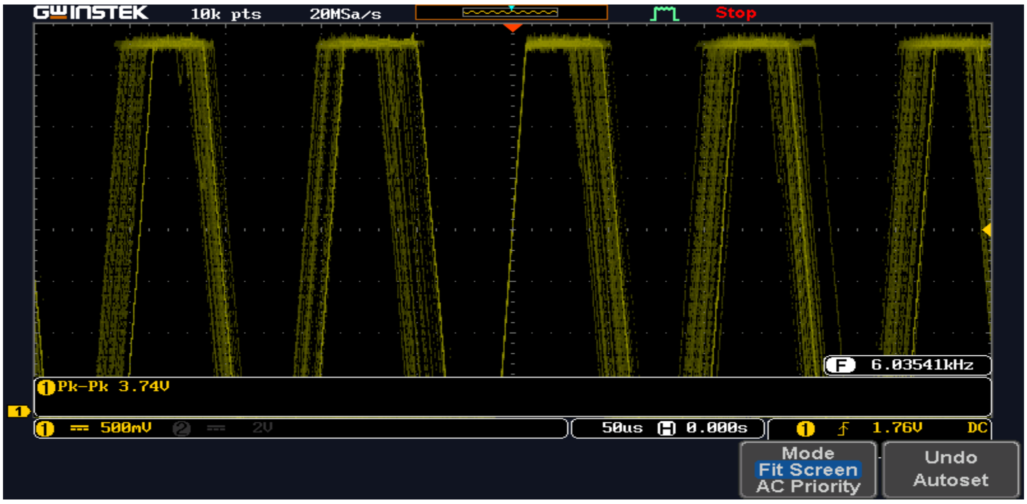


Fig 5.5: (a) Rain mode: medium and **(b)** Receiver side frequency with rain rate 72mm/min

5.3.5. Receiver side frequency (heavy mode)

In this case for the sake of the experimental purpose the regulator node is further released which increases the flow of the water thus increasing the rain rate, this case is being denoted as heavy mode as it depicts heavy rain shower in the natural condition. In this case the rain rate is measured to be 90mm/min.

In receiver side, it is found that 9.78 KHz frequency changes to5.80 KHz frequency in this situation. That is shown in **Fig. 5.6**

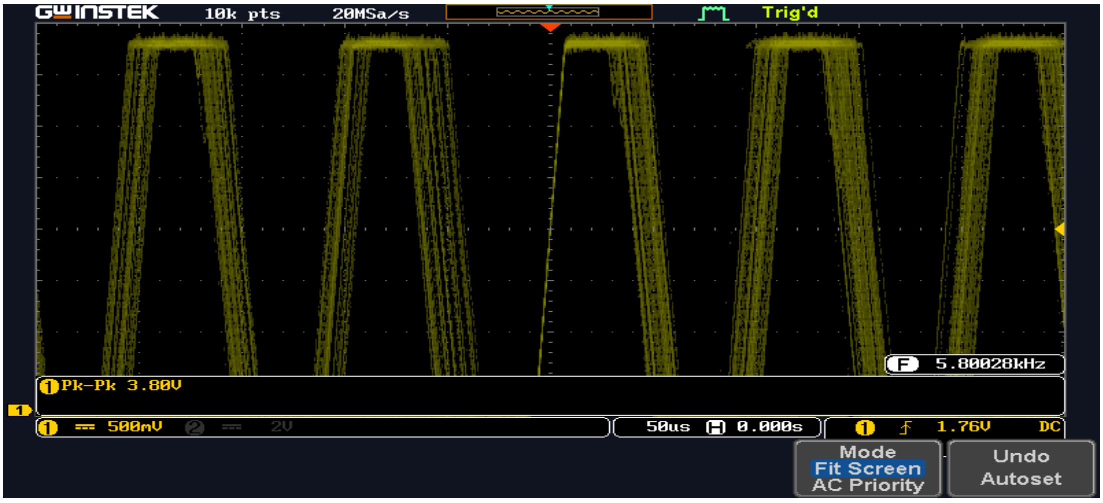


Fig 5.6: (a) Rain mode: heavy and **(b)** Receiver side frequency with rain rate 90mm/min

Thus by observing the data which is received by performing the above experiment a graphical representation can be plotted which is shown in **Fig. 5.7.**

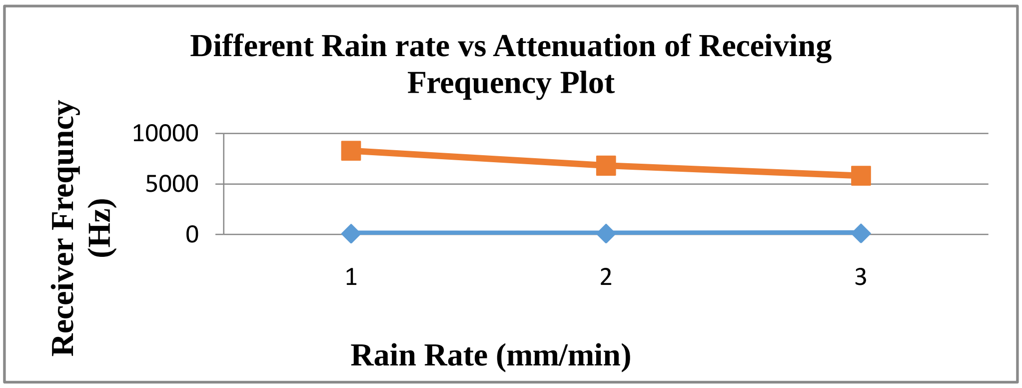


Fig 5.7: Different rain rate vs. attenuation of receiving frequency plot

5.4. Conclusions

From the above results obtained with the help of power meter and oscilloscope, from the receiver end, there is a significant amount of attenuation is observed in the data which is being collected. The frequencies which were collected at the receiver end does not match then frequencies collected at the transmitter end. There is pattern which is also being observed in this experiment, the loss of frequencies are directly proportional to the increase rain rate, and the loss of power is also significantly same. There is also a loss of power in the receiver end of the setup, which also proves that a laser power and laser modulated frequency is heavily related to the rain rates, as there are significant amount of information which was lost during the whole process.

The loss of the power and frequencies can be explained with the knowledge of extinction, which means the reduction in the intensity of a propagation laser beam, as in this case the reduction of the power of the laser of wavelength 808nm. The extinction phenomenon can occur mainly due to two reasons which is absorption and scattering, both of these process remove energy in the direction of laser beam propagation.

Thus it is also observed that the loss of power and frequencies are related to the amount of rain rate as the loss of power and frequencies is directly proportional to the increase in rain rate which depicts the reason that the frequency and the power is being scattered and absorbed.

There is also another characteristic observed in the following experiment, as the frequency of the transmitter and receiver shows the same frequency which is generated by the VCO oscillator at 100 meters between them. This means that there is no attenuation of frequency in free space distance of 100 meters.

Chapter 6:ARTIFICIAL RAIN SIMULATION -II

6.1. Introduction

This chapter is the continuation of the previous chapter(i.e.chapter 6), as in that chapter the study of attenuation of the power of the 808nm laser was conducted it was observed that there was a significant amount of loss in power as the laser beam was channelized through an artificial rain simulation. Similarly with help of same laser a preset frequency was modulated and passed through the artificial rain simulation, in this case also there was a notable quantity of loss depicted in frequency data. The previous experimental investigation had some flaws as the control of the artificial rain simulation was not perfect and the rain rate was notably high in the case of the medium mode and heavy mode. For this reason only, the data acquired from the previous experiment may not prove to be accurate, thus questioning the credibility of the whole experiment.

If the above problem can be foreseen as an anomaly of nature where the received data have been recorded in extreme weather conditions, then there is also another notion which is not explored in the last experiment, which is the study of different wavelength of lasers in the same condition put through as the laser of 808nm. By performing the similar experiment with an improved and controlled rain rate and with different wavelength of lasers involved in this experiment can give a more in-depth review of the nature of the attenuation seen. The nature of the attenuation is very important in this experiment, as it can be monitored in understanding if lasers of different wavelengths attenuate differently or individually or all the lasers have same attenuation rate when it is passed through the artificial simulated rain water as the rain rate is changed or varied.

By conducting this experiment with the new setup where the rain rate is much improved and also relatable with the real rain-rate like feature, as the help of power meter the power of different wavelength can be also measured. This would give a versatile formation and a good view of the loss or attenuation of power through artificial rain, as in the previous experiment the loss of power was also observed.

6.2.Experimental Plan and Setup

This experiment is the direct continuation of the previous experiment with the same notation of observation, as the object of the communication system is to transfer data or information from a transmitter at one point to a receiver at another through the intervening atmospheric channel with an acceptance error rate while providing high reliability. In this set of experiments the transmitter consists of different lasers, with its laser module and laser driver, the laser driver draws 12 V and the module around 5 V. The modulator converts bits of information into electrical signal and modulates the laser to generate an optical signal, in this particular experimental setup, 19 kilo hertz is formulated, but the transmitting signal may vary in each sub-part of the experimental condition due to the formulation of laser driver which modulates the signal and other reason is the oscillator used in this experiment is VCO oscillator where the transmitting frequency is changeable.The optical signal propagates through the atmospheric channel and is collected by the receiver to recover the data. On the receiver side it consist of a detector and a decoder to get the signal out, in this experiment the decoder used is BPW34 which is a semiconductor photo as the detector converts the optical signal back to an electrical signal.Thus by this process the prolonged experiment will be performed by transmitting a preset specified frequency with the help of the modulator and laser module, which will be beamed via 808 nm laser. The modulated beam will be passed through rain, which is artificially simulated, and then it will be received at the other side, which is the receiver end,with the photo detector placed to demodulate the frequency carried laser beam. Then that signal is formulated and analyzed to have a thorough in-depth knowledge on the attenuation of the laser beam with its loss of the data sent.

In this particular experiment same type of lasers are used which is a DPSS (Diode Pumped Solid State Laser) but as in the previous experiment only one laser was used which was infrared in nature and its wavelength was 808nm. But in this set of experiment same type of laser is being used but the wavelengths are different. As five lasers have different wavelengths such as 450nm,532nm,638nm, 808nm 980nm.

In the previous experiment it was conducted in a very low light artificial light , but in this experiment the whole setup is in open air under the sky . This was done mainly due to gain more realist data and to have a notch ahead in collection of the data under real atmospheric condition as the whole experiment is based on the collection of the attenuation. By performing it in the open air the chances of attenuation is significantly higher, thus proving to have more accurate data in this process.

As in the previous experiment the rain rate was significantly higher thus causing a huge set back in the whole process and observing the data acquired in that experiment was bit high, thus control of the rain rate was very important aspect of this new experiment . The built and setup of the new experiment is entirely different from the previous one as new and dedicated structure was made and built for this purpose only . The structure is made up of pure iron rods of 6mm diameter as the structure is like a rectangular hollow box with it length is 15 feet and breath is 3 feet and height is 10 feet, with 16 showers of 4 inch are fitted, at the top of the iron structure with set of two showers each with difference of 0.5ft between to shower setsas there will be 8 sets of shower pair. There is a gap of 2 feet from the two openings of the series of shower pair from the distribution of weight of the body. The showers are systemically connected with 1 inch water pipe individually in a serial manner to have the water being distributed downwards as a form of artificial rainfall. The showers are then connected to 6 feet long pipe to secondary water line which is also has 8 ball valve of 3/4 inch as it has been used to control the flow of water as to control the artificially simulated rainfall. The secondary water line is connected to the main water line with the help of 3/4 inch UPVC pipe of the length 17.5 feet. As the end of the pipe is submerged in the water which is contained by water tank of dimension of 2.4×2.4×1.2 feet which stores approximately 250 liters of water. There is also another section of pipe inserted to the water tank kindly denoted as "excess pipe" which is installed in the outflow section of the secondary pipe line. The purpose of the excess pipe is installed to check the pressure of the pipe inserted by the pump and to avoid the wastage of water which happens in filling up the water in the tank. The tank is filled with water with the help of 5 feet long water pipe and the outlet of the water tank is connected via help of 1 inch flexible pipe to the 0.5 horsepower pump as the pump is then connected to the opening of the secondary water pipe line of the iron structure system.

In this set of experiment, the distance between the transmitter and the receiver is 11.33 meter or 33 feet (approx), the link is established through the iron structure as the structure is hollow and the link is based at the middle of the structure right underneath the shower which would simulated artificial rain, as the modulated signal will be passing through it. The transmitter and the receiver are placed 7 feet from the artificial rain chamber, so as to primary protect the laser and its module and other instruments used in this process but also to have a clear view of the whole process and to take a valid and easy readings of the instruments. The hydraulic pump inlet in then submerged in the 500 liters water tank, where the desired water is kept. The water used in the experiment is freshwater with no to little amount of salt and impurities added. The whole process starts with the water tank being filled with freshwater with the help of a local water source and then the tank is being fully filled, which allows the experiment to move into its next stage. Then the hydraulic pump is turned on with its power it channelizes the water via pipe to the secondary water line to its primary water line then to the showers. After that the artificial rain simulation starts. With the help of ball valve the control of the rain rate is possible as it controls the amount or force of the water inserted by the pump to the shower which then falls on the link established.By this process the control of the rain rate was achieved, which helped to have a clearer and in-depth analysis of the attenuation of the power of the laser beam and the frequency modulated into the laser beam. The power meter mentioned above is being thoroughly used at the receiver end of the aligned laser link.After that the photo is being used to acquire the modulated signal with the help of an oscilloscope thereafter the received frequency is observed. On the receiver side of the system the photo detector and the oscilloscope require 5 volts and 12 volts respectively, which is then provided by the variable DC power supply. In this particular experiment another set of oscilloscope and variable DC power supply was required on the transmitter side of the setup where it provided 5 volts to the module of the laser system and 12 volts to the main laser device. The oscilloscope was being used as to determine the preset frequency of the modulated laser signal before the attenuation through the artificial rain so as to give a platform by which the comparison can be made by how much the attenuation is considered. But in this set of experiments the laser on the transmitter side used are more than one laser as it was used in the previous experiment which defines the new experiment more challenging and hard as the establishment of the link is very tough.

In this experiment the variation of the rain rate is very important where the rain rate is varied by the use of ball valve thus increasing the study of the attenuation of the nature of the laser in a further more in depth manner. The study of the rain rate is done by using rain gauge which is then put under the artificial rain simulator , the rain rate is measured in the unit of mm/min way. This process is used to have a more practical approach in the simulator and also to save water. But then it was converted to the normal measuring unit of mm/hr.

In this experiment the attenuation of the lasers are calculated in form of percentage as,

$$\text{Resultant Power} = \frac{\text{Power received after passing through rain}}{\text{Total power received before passing through rain}} \times 100$$

Power Loss = (100 - Resultant Power) %

$$\text{Resultant frequency} = \frac{\text{Frequency received after passing through rain}}{\text{Frequency received before passing through rain}} \times 100$$

Frequency Attenuation = (100 - Resultant Frequency)%

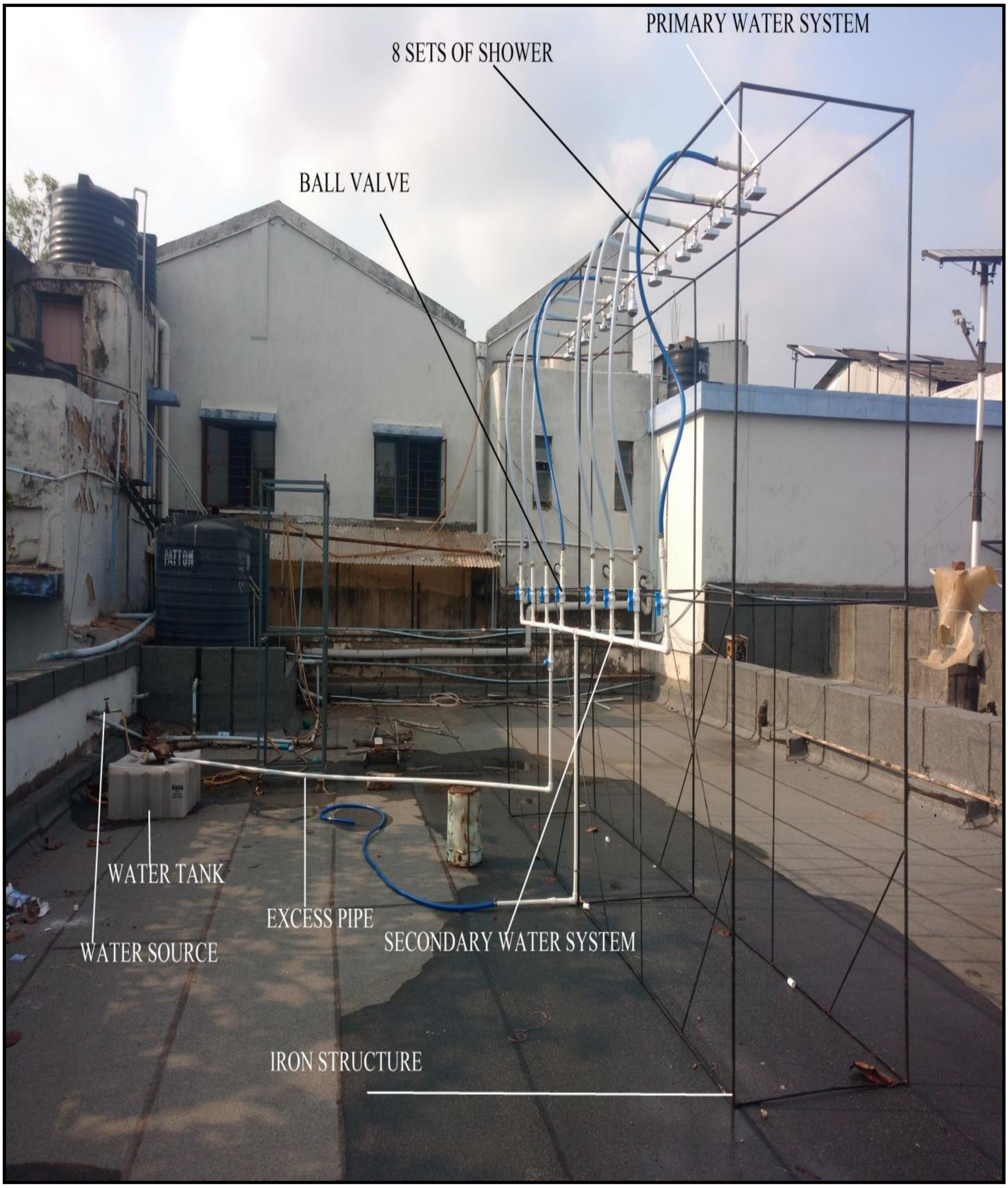
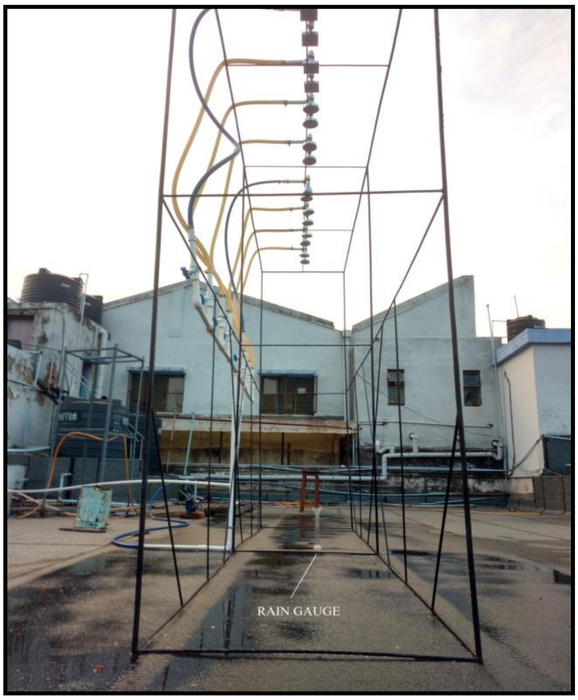


Fig.6.1: Experimental setup of rain at transmitter side & receiver side

(a)



(b) (c)

Fig.6.2: (a), (b) and **(c)**Experimental setup of artificial rain simulator

6.3. Experimental results

As mentioned earlier in the above, the experiment is being conducted with varying the rain-rate by using the ball valve in the secondary water system to have an in depth knowledge of the nature of the attenuation caused by the rain to the modulated frequency carrying the signal. Thus the experiment is done in primarily three parts excluding the data collected without rain, which is light mode (light rain), medium mode(medium rain) and heavy mode(heavy rain) as in this set of experiment different lasers are used which is shown in **Table 6.1.**

Table 6.1: Experimental Result of Rain Simulation with different Parameters

Sl. No	Wavelength (nm)	Rain rate	Distance (m)	Power(mW)		Frequency(kHz)	
				Without rain	With rain	Without rain	With rain
1	**450**	**High**	11.33	71.3	43	20.591	13.764
		medium	11.33	71.3	52	20.591	17.601
		Low	11.33	71.3	58	20.591	18.996
2	**532**	**High**	11.33	51	22	20.401	17.146
		medium	11.33	51	27.6	20.401	18.421
		Low	11.33	51	43	20.401	20.267
3	**638**	**High**	11.33	38.7	10.03	20.444	9.887
		medium	11.33	38.7	15.50	20.444	12.582
		Low	11.33	38.7	27.7	20.444	17.192
4	**808**	**High**	11.33	7.05	4.5	21.074	11.716
		medium	11.33	7.05	5	21.074	14.891
		Low	11.33	7.05	5.8	21.074	16.014
5	**980**	**High**	11.33	4.5	3	20.398	11.629
		medium	11.33	4.5	3.4	20.398	14.542
		Low	11.33	4.5	4	20.398	18.871

6.4.Analysis and measurement of the attenuation of individual lasers

As, in these particular experiments there are more than one usage of lasers thus giving a profound analysis of the individual laser is very important as there are five laser used in this setup. The measurement of the loss in very unique task which upholds the signifies of the performing this experiment, the analysis of different laser are as follows:

6.4.Laser wavelength of 450nm

The 450nm laser is visible to the naked eye as it emits purple color concentrated laser beam ,the laser is manufactured with the power of 400mW. As shown in **Table6.2** given below.

Table 6.2: Experimental Result of Rain Simulation of 450nm laser

Sl. No.	**Wavelength (nm)**	**Distance (m)**	**Rain rate**	**Power (mW)**		**Power loss** (%)	**Frequency (kHz)**		**Frequency attenuation** (%)
				Without rain	**With rain**		**Without rain**	**With rain**	
1	450	11.33	**High**	71.3	43	39.70	20.591	13.764	33.18
		11.33	**medium**	71.3	52	27.07	20.591	17.601	14.52
		11.33	**Low**	71.3	58	18.66	20.591	18.996	7.75

6.4.1.1.Frequency variation in different rainy conditions using digital oscilloscope

It is been observed that with the change in the rain rate in the experiment there is a significant change of the frequency in the receiver end which is fairly related to the amount of rain falling on the laser link by the rain generated artificially. There is also the decline in the power as well, as the amount of loss is directly proportional to the increase of the rain rate, which is also similar as an account of the case of frequency. In this experiment the transmitter and receiver oscillators are phased together.

6.4.1.2.Frequency profile at transmitter and receiver end

A. Frequency profile at transmitter end

As mentioned earlier the experiment is been conducted to find out an in-depth analysis of the attenuation of the frequency and power of laser modulated beam with a preset frequency passed through the artificially simulated rain, thus to study the loss of the frequency of the laser the frequency from the transmitted side has been taken as a point of source and plays a vital role in comparison with the other frequencies which is collected at the receiver side. In transmitter side, it show that 20.591 KHz transmitted in **Fig 6.3.**

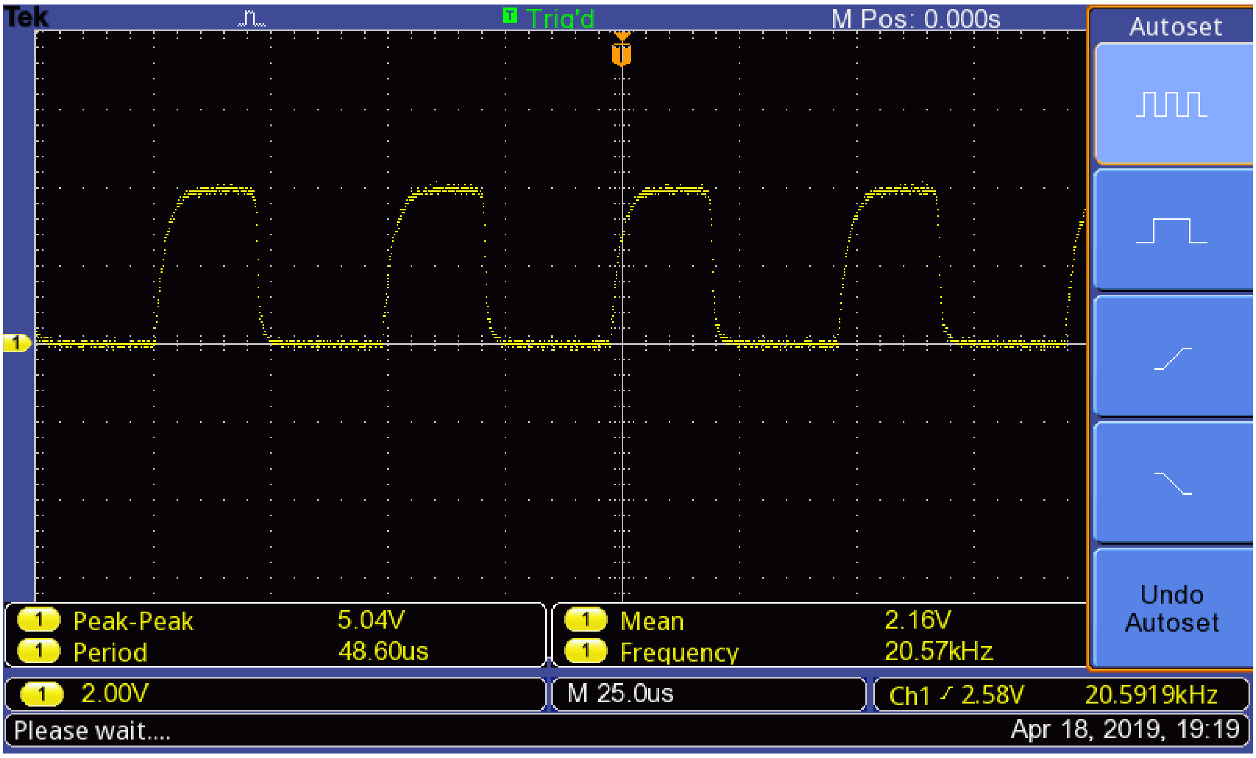


Fig.6.3: Frequency profile at transmitter end

B. Receiver Side Frequency (Without Rain)

In receiver side, it has been shown that20.591KHz received in **Fig. 6.4**.

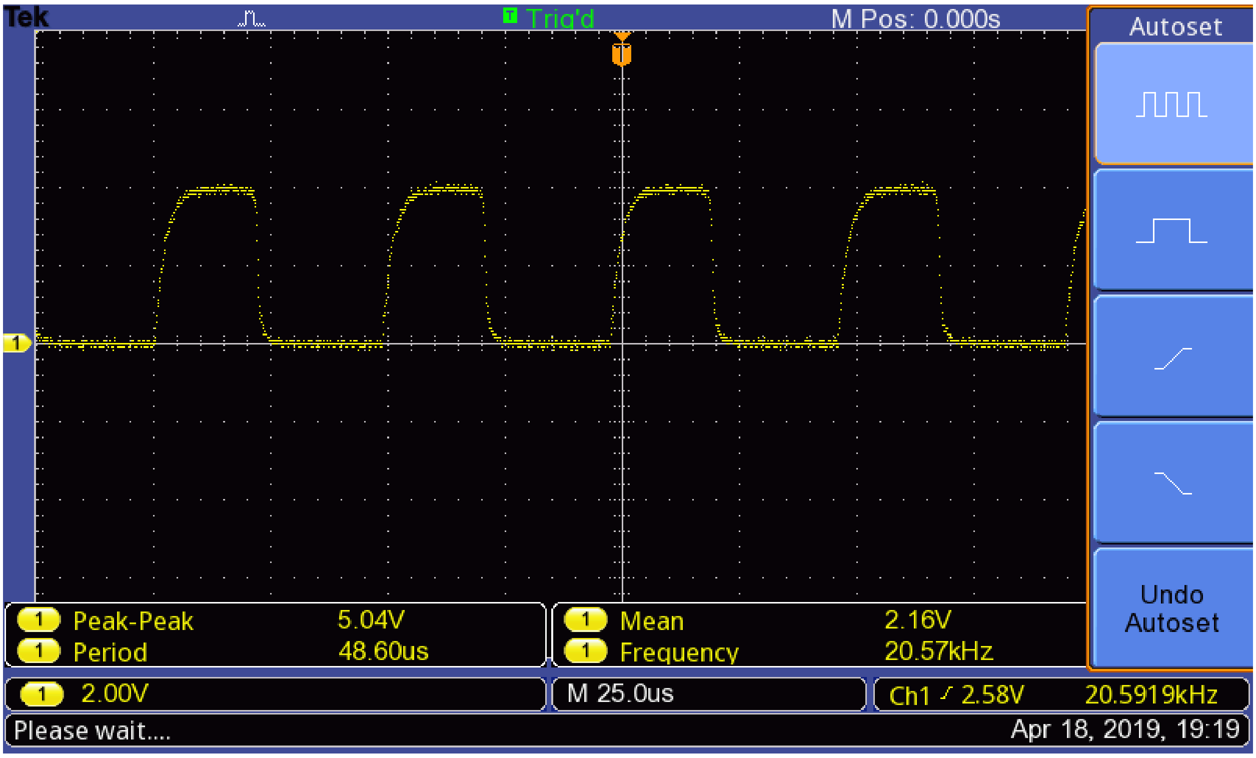


Fig.6.4: Receiver side frequency without rain

6.4.1.3.Receiver side frequency (light mode)

In this case the experiment is been conducted with help of ball valve which is used in the secondary water line system where the flow of water is been controlled as in result the water which is entered to the primary section of the rain water system is less, thus the rain rate is significantly less. The rain rate recorded is 15 ml/hr. **Fig.6.5**shows data at the receiver side, where 20.591KHz frequency becomes 18.99KHzfrequency in this situation.

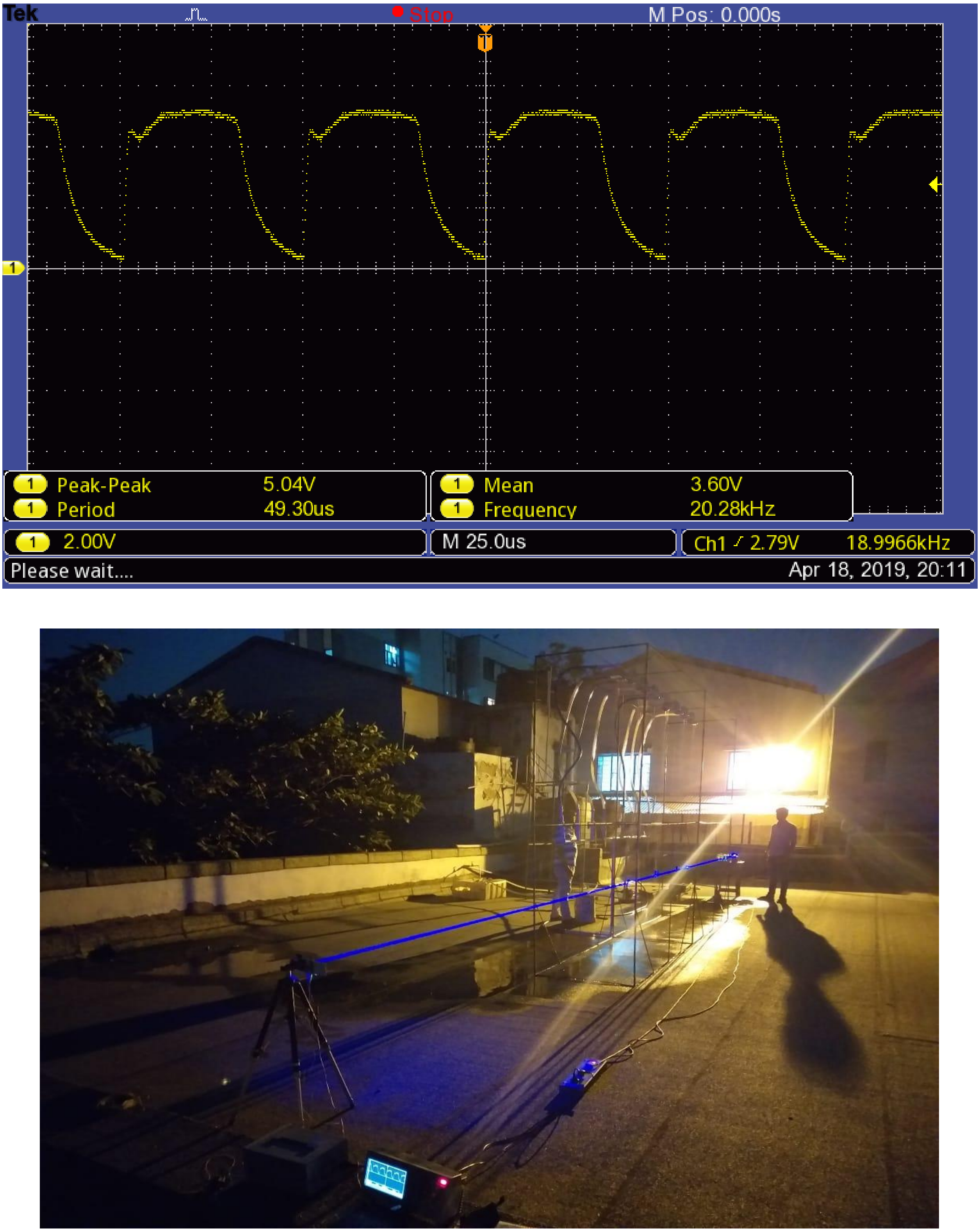


Fig 6.5: Receiver side frequency with rain rate 15mm/hr

6.4.1.4. Receiver side frequency (medium mode)

The amount of water is entering the instrument is further changed as the ball valve is released a bit where resulting in the increase of the amount of water in the primary water system, which increase the rain rate of the system, thus the rain rate increased to the point which was recorded to have rain rate 30mm/hr.

In receiver side, the 20.591KHz frequency has been degraded to 17.60 KHz frequency in this situation. That has been shown in **Fig 6.6**.

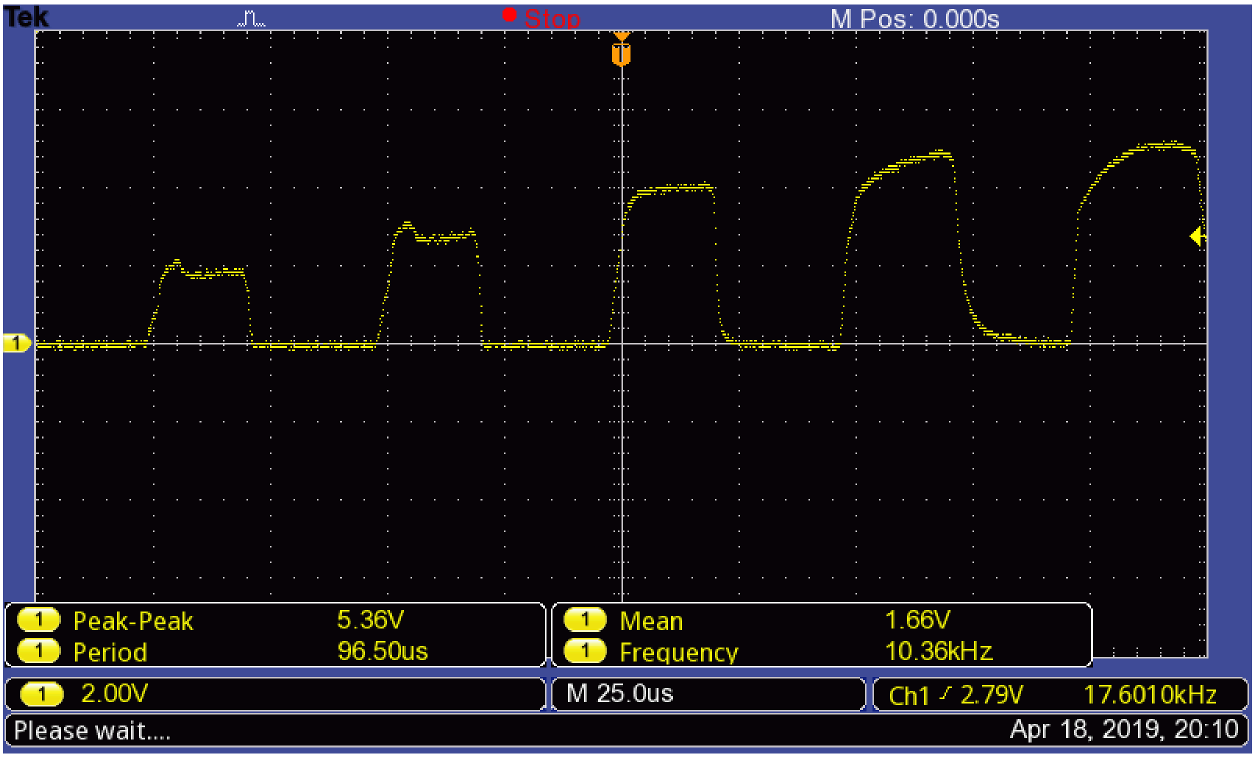


Fig.6.6: Receiver side frequency with rain rate 30mm/hr

6.4.1.5.Receiver side frequency (heavy mode)

In this case for the sake of the experimental purpose the ball valve is further released which increase the flow of the water thus increasing the rain rate, this case is being denoted as heavy mode as it depicts heavy rain shower in the natural condition. In this case the rain rate is measured to be 50mm/hr.

In receiver side, it is found that 20.591KHz frequency changes to13.76 KHz frequency in this situation. That has been shown in **Fig. 6.7.**

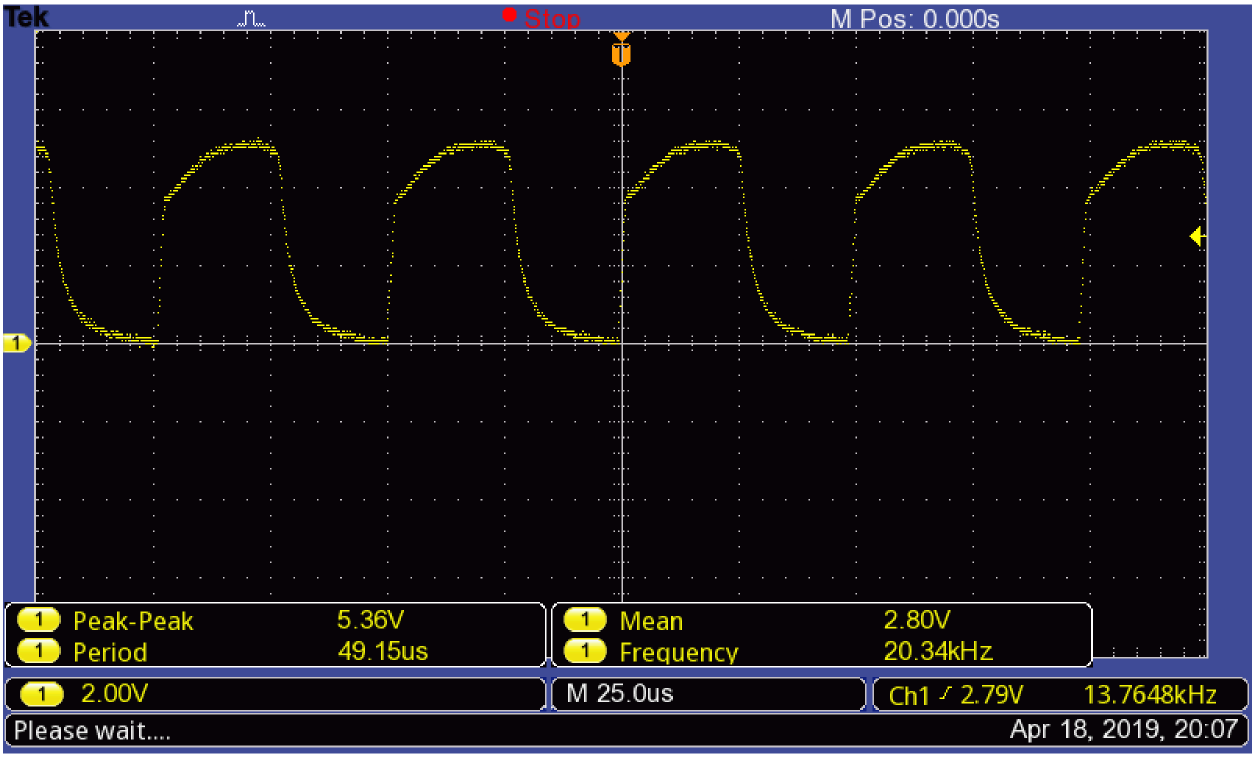


Fig.6.7: Receiver side frequency with rain rate 50mm/hr

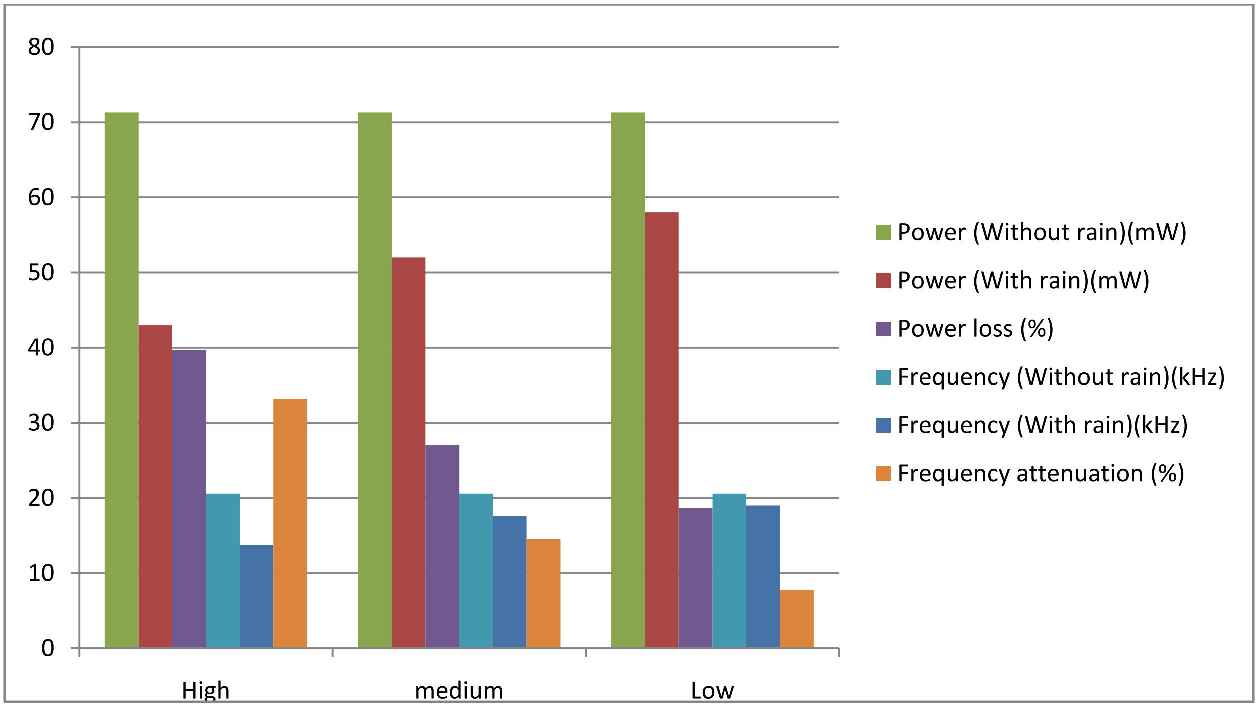


Fig 6.8: Graphical representation of 450 nm laser experiment

6.4.2. Laser wavelength of 532nm

The 532nm laser is also visible to the naked eye as it emits green color concentrated laser beam, the laser is manufactured with the power of 400mW. As shown in the **Table 6.3** below.

Table 6.3: Experimental result of rain simulation of 532nm laser

Sl. No.	**Wavelength (nm)**	**Distance (m)**	**Rain rate**	**Power (mW)**		**Power loss** (%)	**Frequency (kHz)**		**Frequency attenuation** (%)
				Without rain	**With rain**		**Without rain**	**With rain**	
1	532	11.33	**High**	51	22	57	20.401	17.750	15.98
		11.33	**medium**	51	27.6	45.89	20.401	18.421	9.71
		11.33	**Low**	51	43	15.69	20.401	20.267	0.65

6.4.2.1. Frequency variation in different rainy conditions using digital oscilloscope

It is been observed that with the change in the rain rate in the experiment there is a significant change of the frequency in the receiver end which is fairly related to the amount of rain falling on the laser link by the rain generated artificially. There is also the decline in the power as well, as the amount of loss is directly proportional to the increase of the rain rate, which is also similar as an account of the case of frequency.

6.4.2.2. Frequency profile at transmitter and receiver end

A. Frequency profile at transmitter end

As mentioned earlier the experiment is been conducted to find out the in-depth analysis of the attenuation of the frequency and power of laser modulated beam with a preset frequency passed through the artificially simulated rain , thus to study the loss of the frequency of the laser the frequency from the transmitted side has been taken as a point of source and plays a vital role in comparison with the other frequencies which is collected at the receiver side. In transmitter side, it show that 20.401 KHz transmitted in **Fig 6.9.**

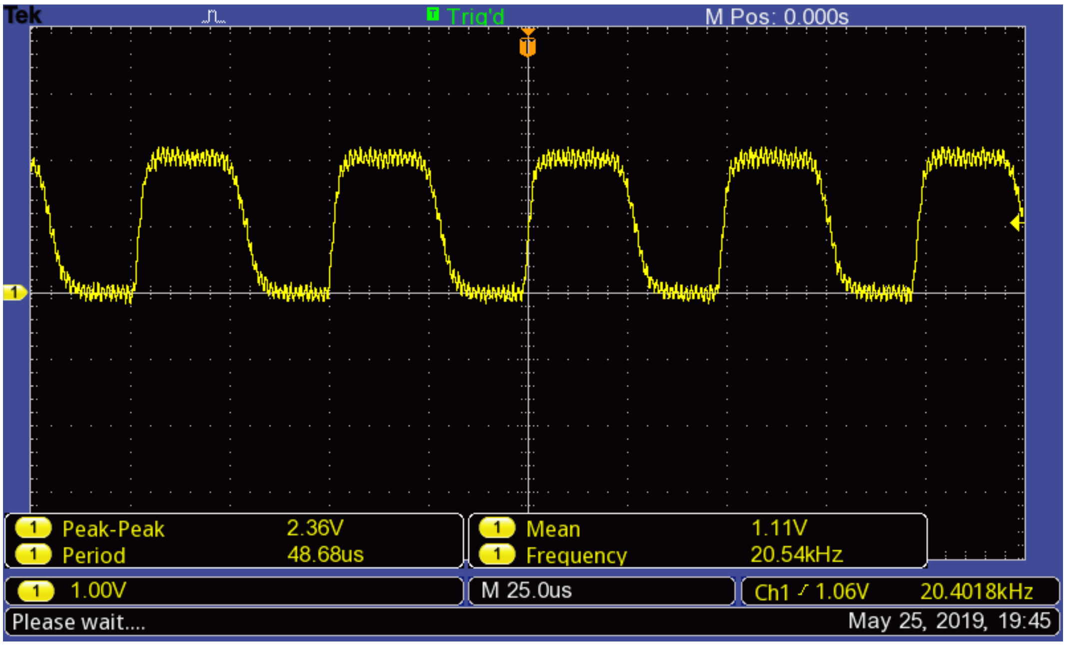


Fig 6.9: Frequency profile at transmitter end

B.Receiver side frequency (without rain)

In receiver side, it has been shown that 20.401 KHz received in **Fig. 6. 10.**

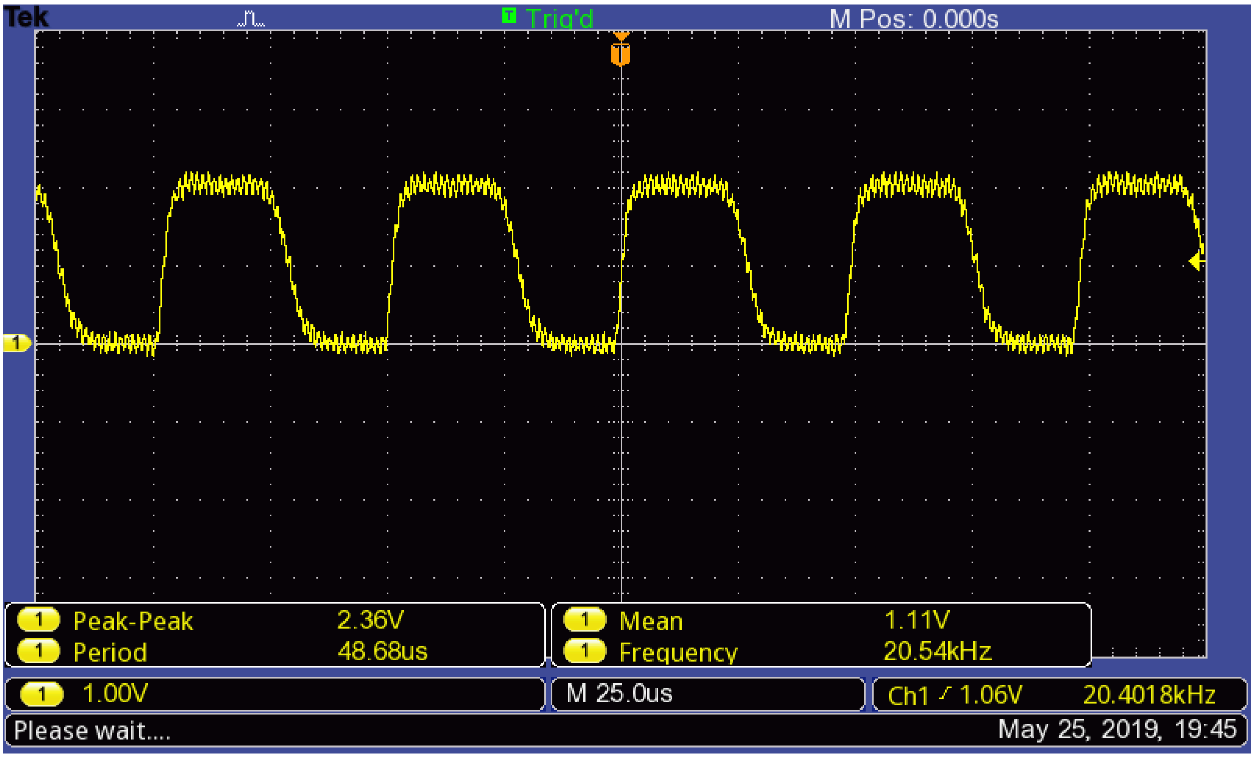


Fig 6.10: Receiver side frequency without rain

6.4.2.3. Receiver side frequency (light mode)

In this case the experiment is been conducted with help of ball valve which is used in the secondary water line system where the flow of water is been controlled as in result the water which is entered to the primary section of the rain water system is less, thus the rain rate is significantly less. The rain rate recorded is 15 mm/hr.

Fig.6.11shows data at the receiver side, where 20.401 KHz frequency becomes 20.267 KHz frequency in this situation.

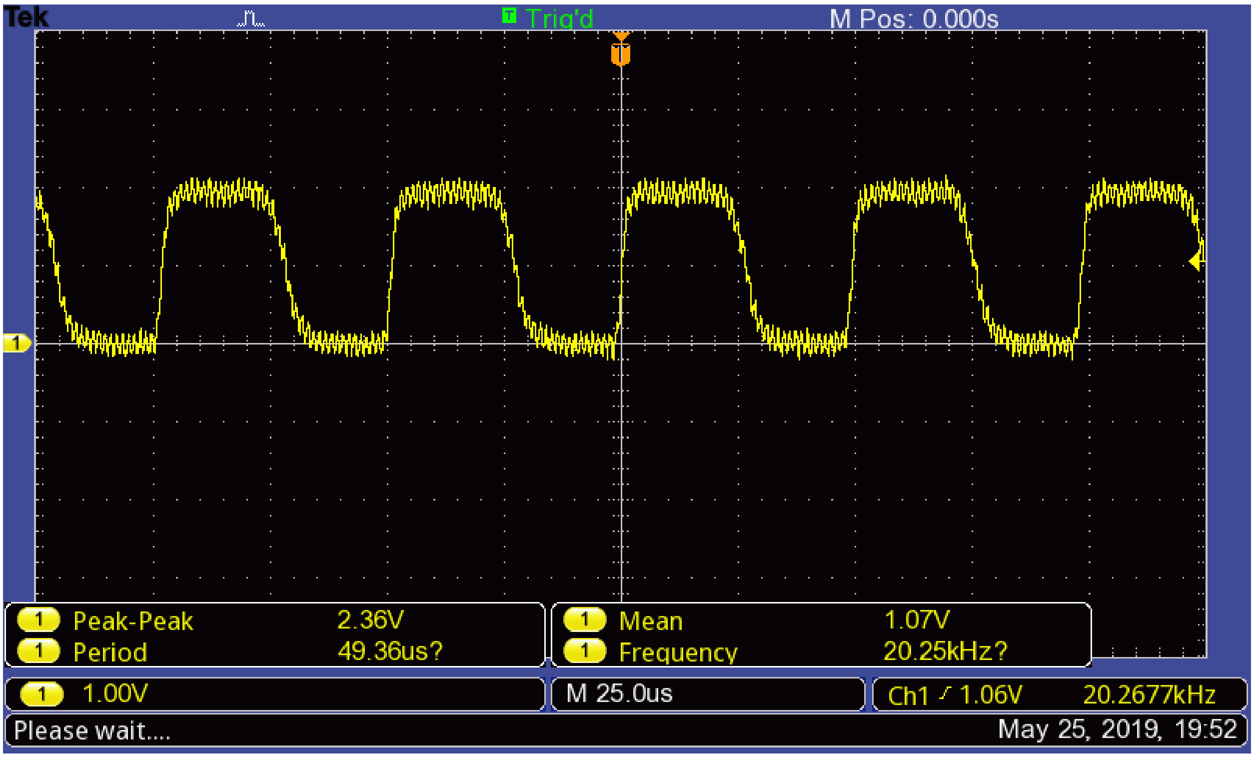


Fig 6.11: Receiver side frequency with rain rate 15mm/hr

6.4.2.4. Receiver side frequency (medium mode)

The amount of water is entering the instrument is further changed as the ball valve is released a bit where resulting in the increase of the amount of water in the primary water system, which increase the rain rate of the system, thus the rain rate increased to the point which was recorded to have rain rate 30mm/hr.

In receiver side, the 20.401 KHz frequency has been degraded to 18.421 KHz frequency in this situation. That has been shown in **Fig 6.12.**

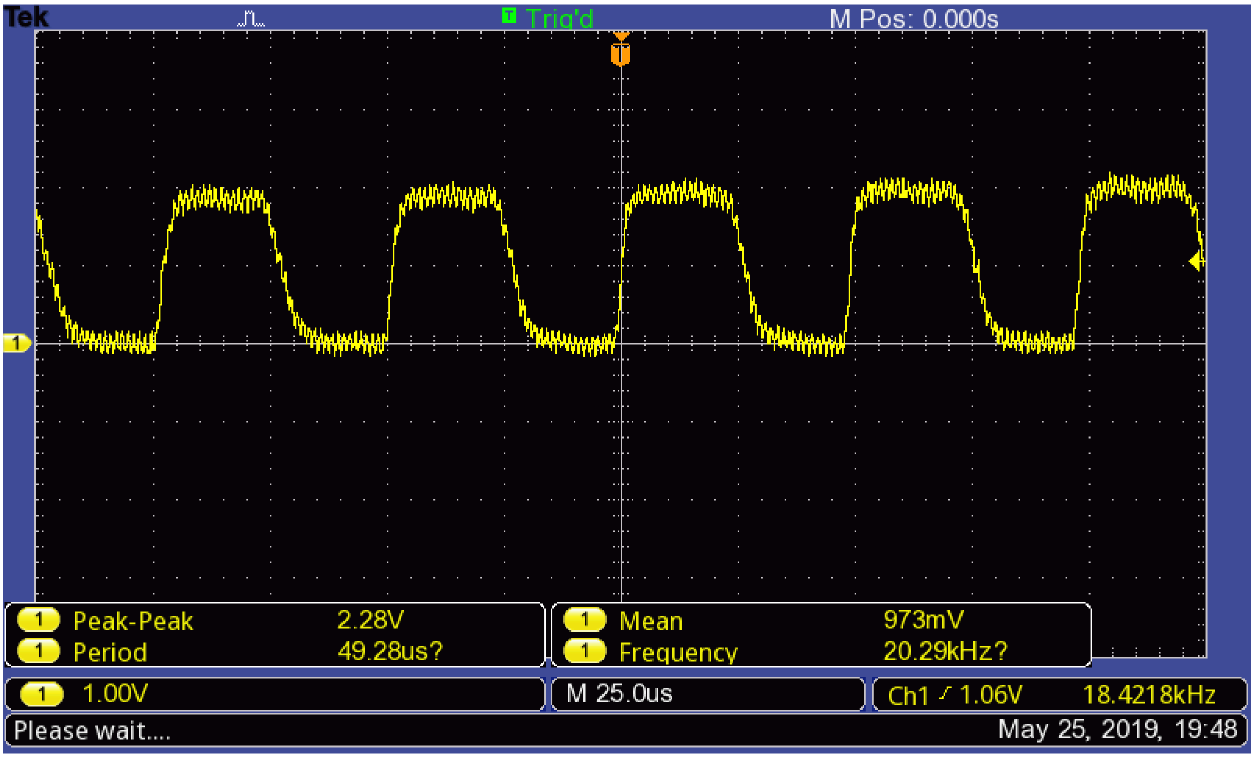


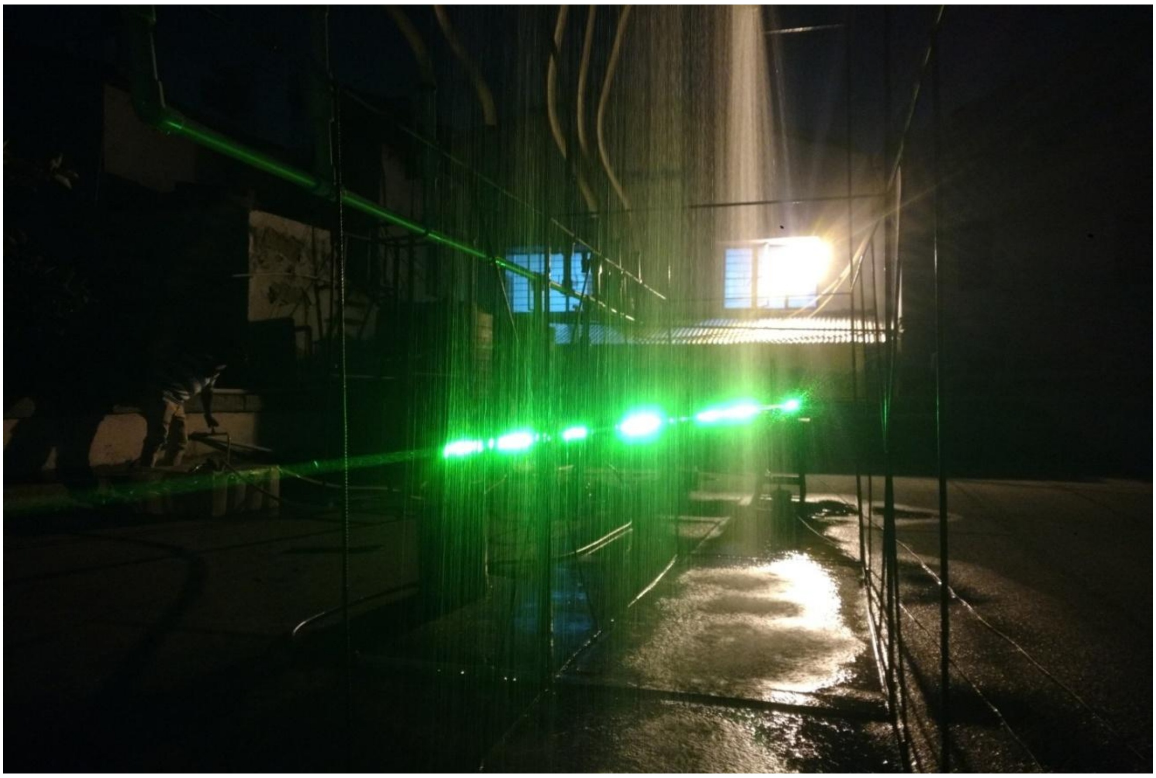
Fig 6.12: Receiver side frequency with rain rate 30mm/hr

6.4.2.4. Receiver side frequency (heavy mode)

In this case for the sake of the experimental purpose the ball valve is further released which increase the flow of the water thus increasing the rain rate, this case is being denoted as heavy mode as it depicts heavy rain shower in the natural condition. In this case the rain rate is measured to be 50mm/hr.

In receiver side, it is found that 20.401 KHz frequency changes to 17.146KHz frequency in this situation. That has been shown in **Fig. 6.13**

Fig. 6.14shows graphical representation of 532 nm laser experiment



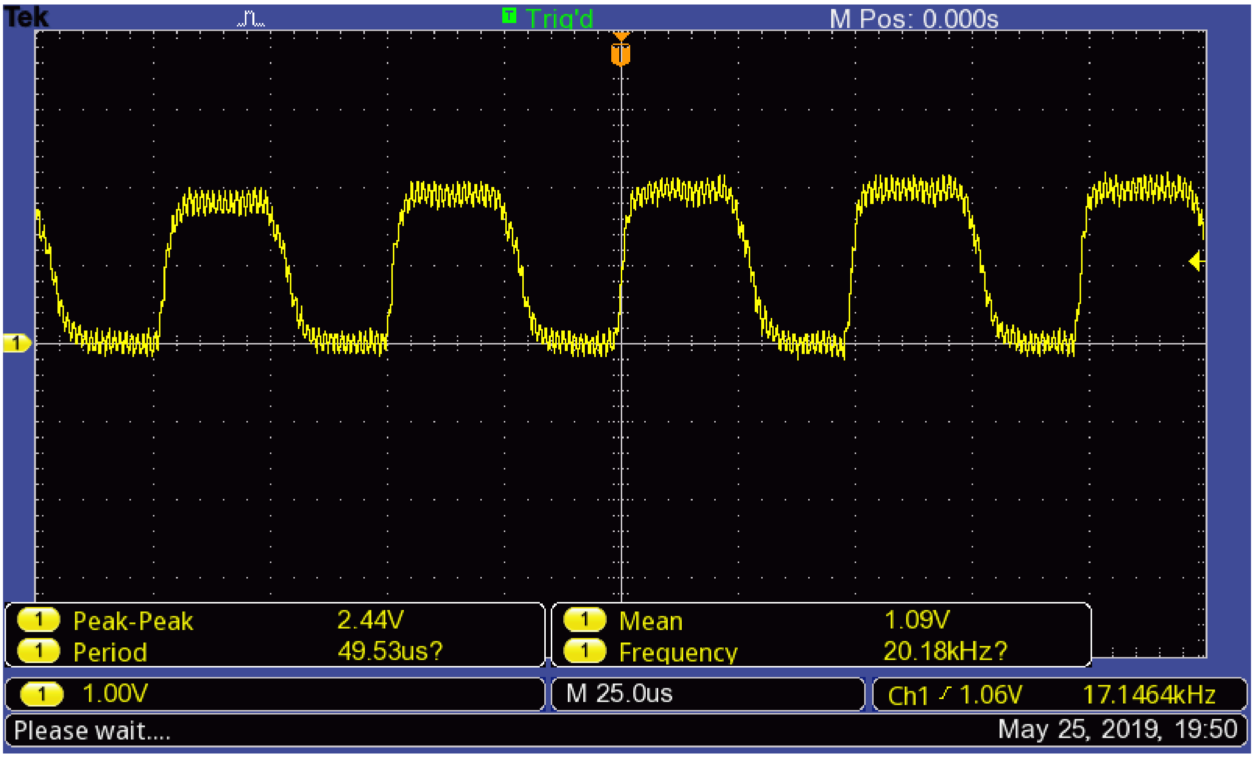


Fig.6.13: Receiver side frequency with rain rate 50mm/hr

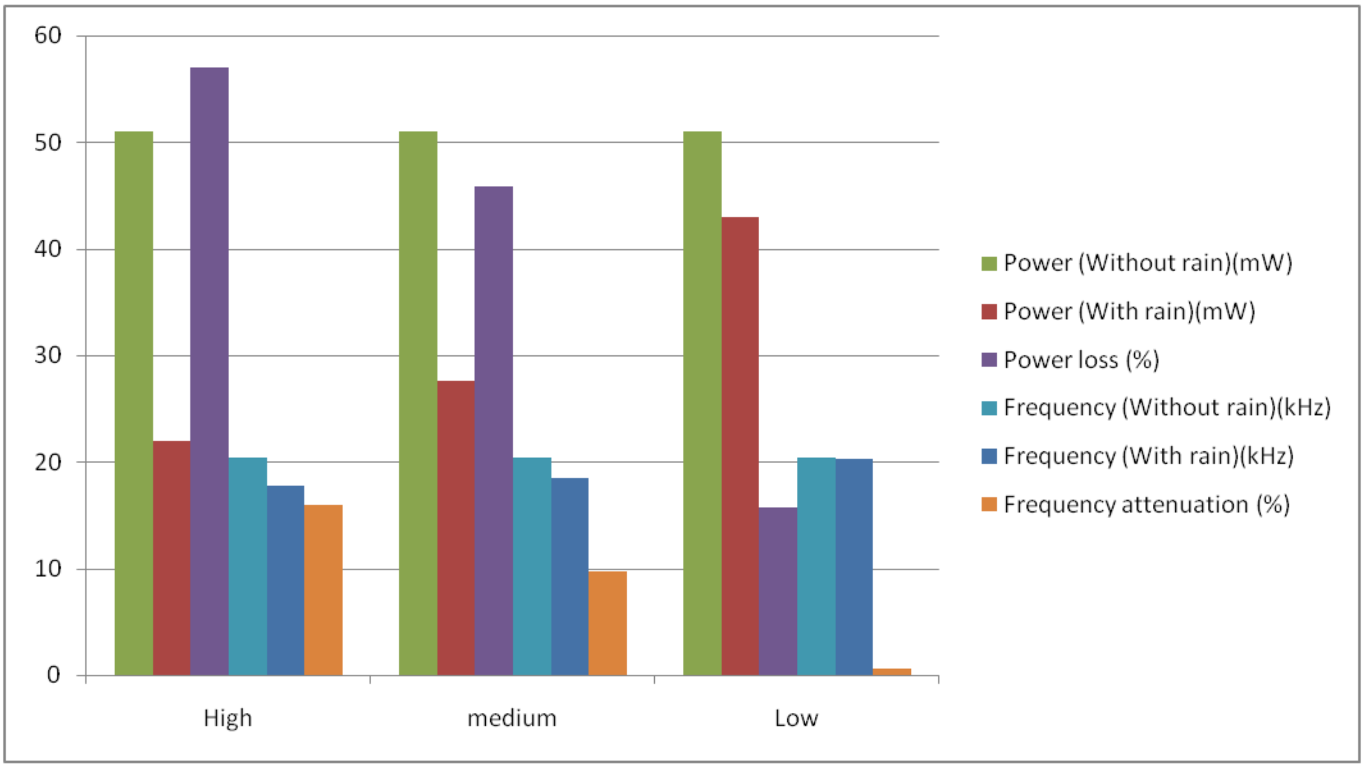


Fig. 6.14: Graphical representation of 532 nm laser experiment

6.4.3. Laser wavelength of 638nm

The 638nm laser is a visible to the naked eye as it emits red color concentrated laser beam, the laser is manufactured with the power of 400mW. As shown in the **Table 6.4** below.

Table 6.4: Experimental Result of Rain Simulation of 638nm laser

Sl. No.	Wavelength(nm)	Distance (m)	Rain rate	Power (mW)		Power loss (%)	Frequency (kHz)		Frequency attenuation (%)
				Without rain	**With rain**		**Without rain**	**With rain**	
1	638	11.33	**High**	38.7	10.03	74.09	20.444	9.887	51.63
		11.33	**medium**	38.7	15.50	59.95	20.444	12.582	38.45
		11.33	**Low**	38.7	27.7	28.43	20.444	17.192	15.90

6.4.3.1. Frequency variation in different rainy conditions using digital oscilloscope

It is been observed that with the change in the rain rate in the experiment there is a significant change of the frequency in the receiver end which is fairly related to the amount of rain falling on the laser link by the rain generated artificially. There is also the decline in the power as well, as the amount of loss is directly proportional to the increase of the rain rate, which is also similar as an account of the case of frequency.

6.4.3.2. Frequency profile at transmitter and receiver end

A. Frequency profile at transmitter end

As mentioned earlier the experiment is been conducted to find out the in-depth analysis of the attenuation of the frequency and power of laser modulated beam with a preset frequency passed through the artificially simulated rain , thus to study the loss of the frequency of the laser the frequency from the transmitted side has been taken as a point of source and plays a vital role in comparison with the other frequencies which is collected at the receiver side. In transmitter side, it show that 20.444 KHz transmitted in **Fig 6.15.**

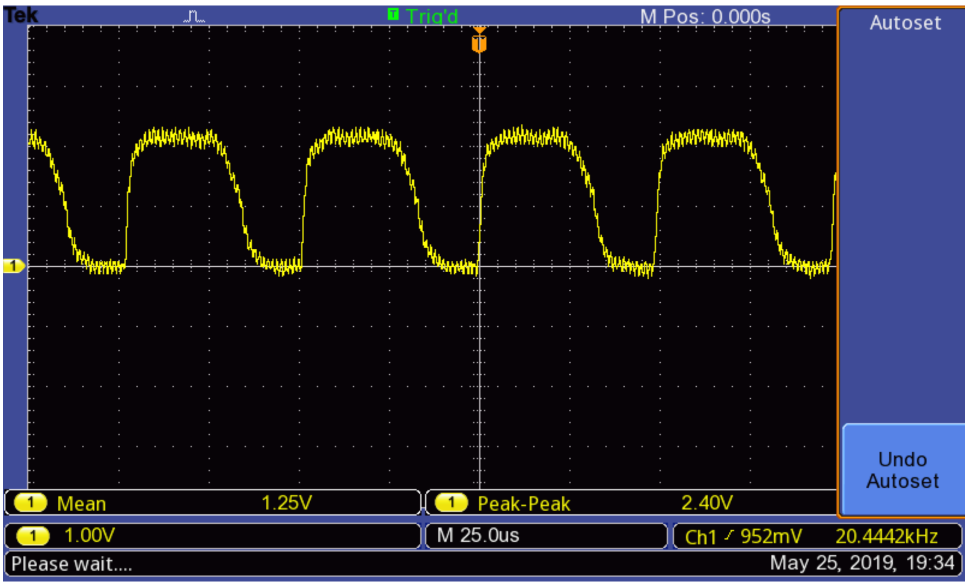


Fig 6.15: Frequency Profile at Transmitter End

B. Receiver side frequency (without rain)

In receiver side, it has been shown that 20.444 KHz received in **Fig 6.16.**

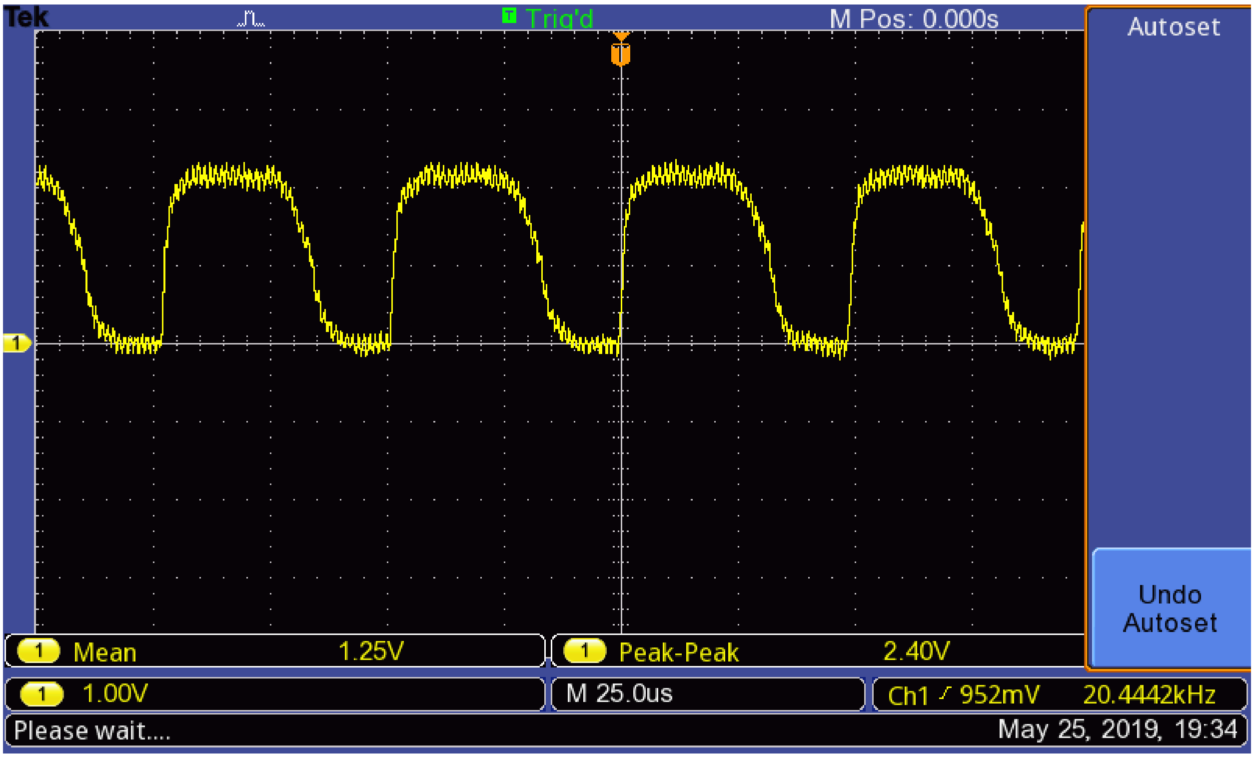


Fig.6.16: Receiver side frequency without rain

6.4.3.3. Receiver side frequency (light mode)

In this case the experiment is been conducted with help of ball valve which is used in the secondary water line system where the flow of water is been controlled as in result the water which is entered to the primary section of the rain water system is less, thus the rain rate is significantly less. The rain rate recorded is 15 mm/hr.

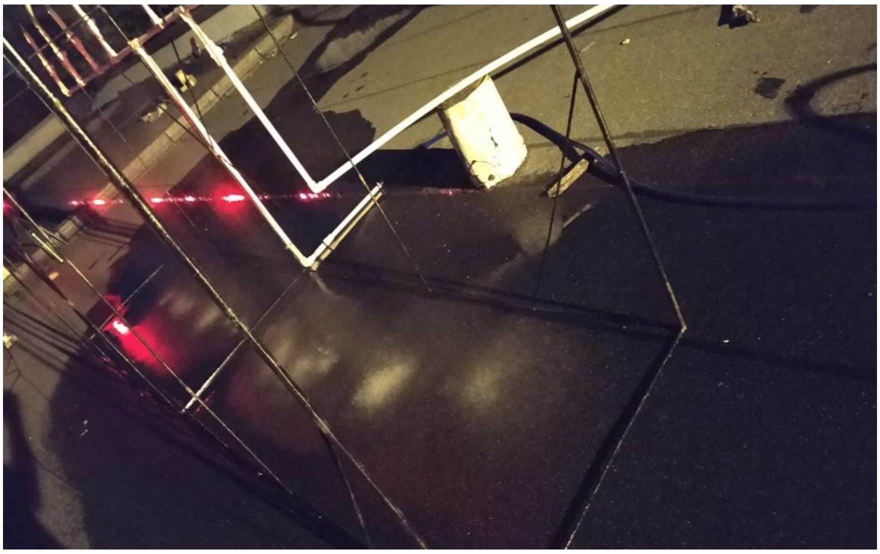


Fig.6.17 shows data at the receiver side, where 20.444KHz frequency becomes 17.192KHz frequency in this situation.

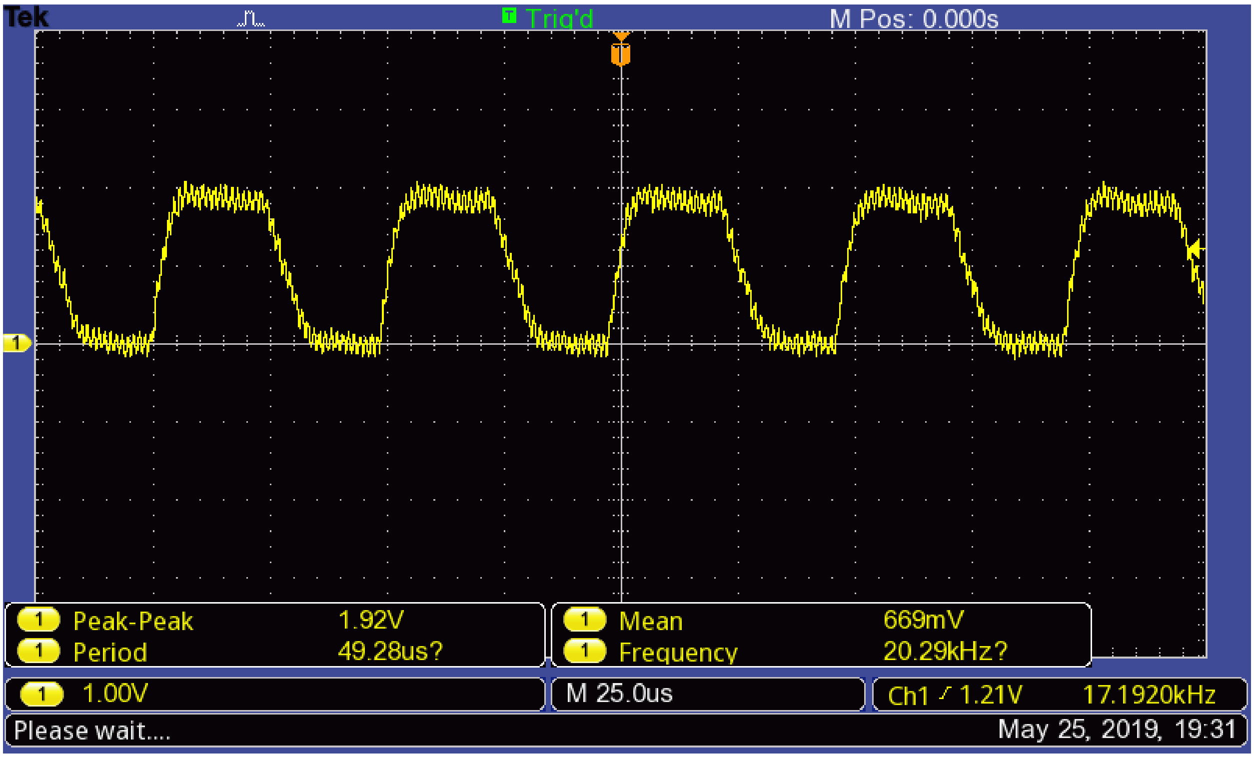
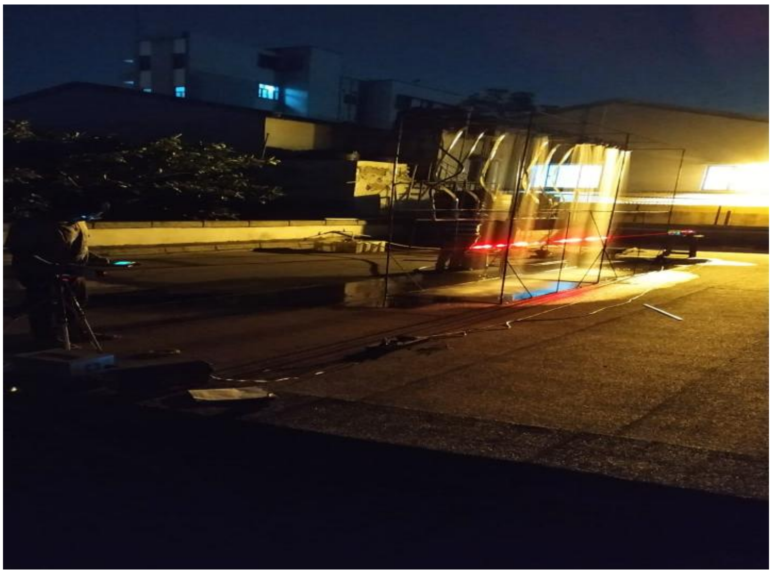


Fig.6.17: Receiver side frequency with rain rate 15mm/hr

6.4.3.4. Receiver side frequency (medium mode)

The amount of water is entering the instrument is further changed as the ball valve is released a bit where resulting in the increase of the amount of water in the primary water system, which increase the rain rate of the system, thus the rain rate increased to the point which was recorded to have rain rate 30mm/hr.

In receiver side, the 20.444 KHz frequency has been degraded to 12.582 KHz frequency in this situation. That has been shown in **Fig.6.18**.



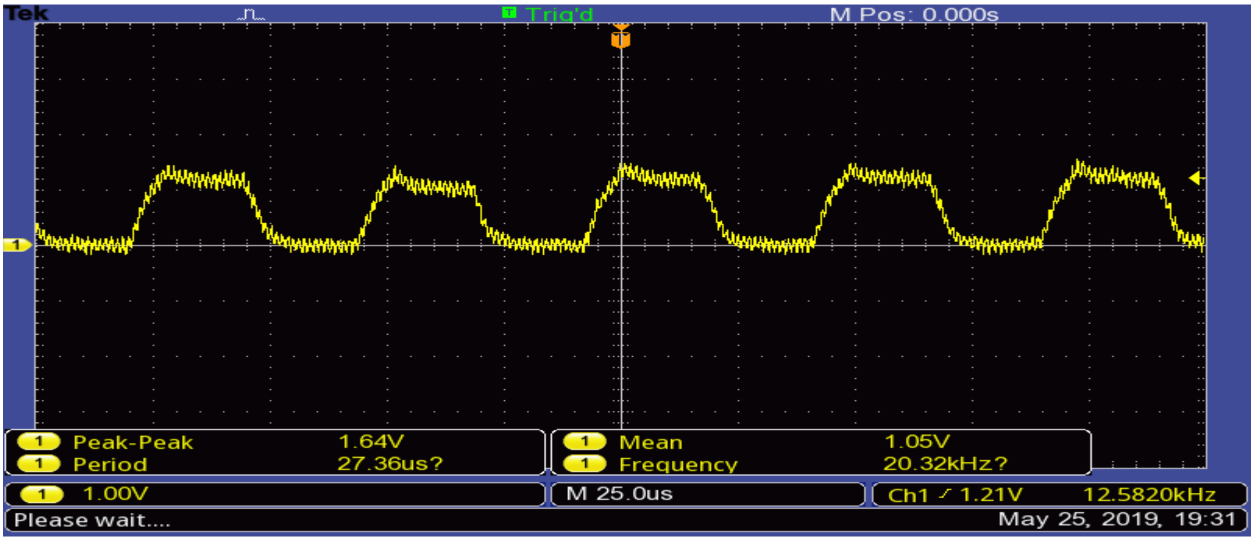


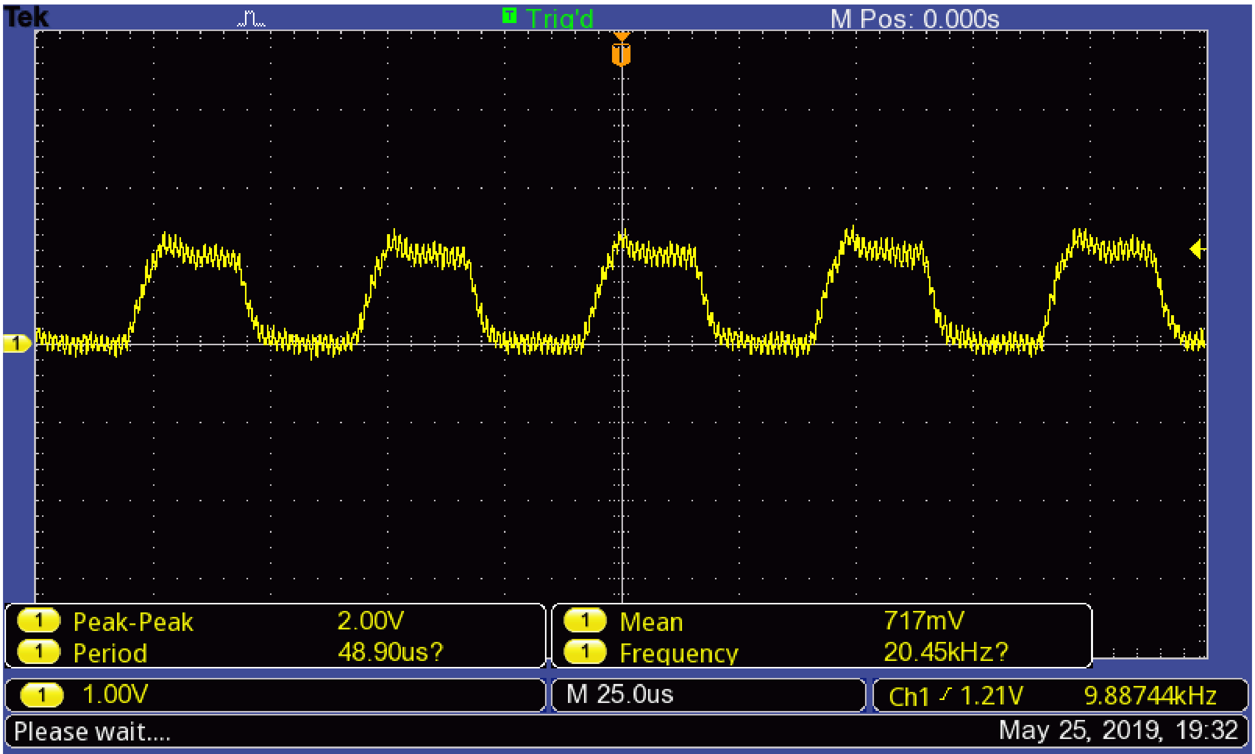
Fig.6.18: Receiver side frequency with rain rate 30mm/hr

6.4.3.5. Receiver side frequency (heavy mode)

In this case for the sake of the experimental purpose the regulator node is further released which increase the flow of the water thus increasing the rain rate, this case is being denoted as heavy mode as it depicts heavy rain shower in the natural condition. In this case the rain rate is measured to be 90mm/hr

In receiver side, it is found that 20.444 KHz frequency changes to 9.887 KHz frequency in this situation. That has been shown in **Fig. 6.19**

Fig 6.20 shows the graphical representation of 638 nm laser experiment



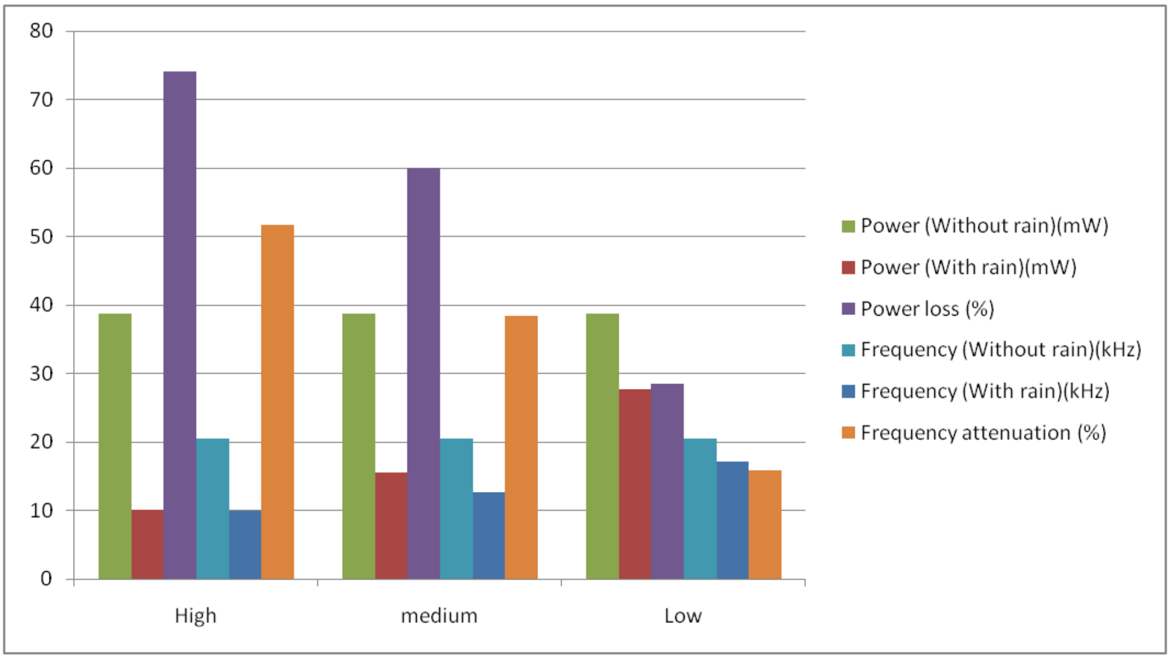


Fig 6.19: Receiver side frequency with rain rate 50mm/hr

Fig 6.20: Graphical representation of 638 nm laser experiment

6.4.4. Laser wavelength of 80 8nm

The 808nm laser is a partly visible to the naked eye as it a infrared laser beam the laser is manufactured with the power of 400mW. As shown in the **Table 6.5**below.

Table 6.5: Experimental Result of Rain Simulation of 808nm laser

Sl. No.	**Wavelength(nm)**	**Distance (m)**	**Rain rate**	**Power (m.W)**		Power loss (%)	**Frequency (kHz)**		Frequency attenuation (%)
				Without rain	**With rain**		**Without rain**	**With rain**	
1	808	11.33	**High**	7.05	4	46.67	21.074	11.716	44.41
		11.33	**medium**	7.05	5	29.08	21.074	14.891	29.34
		11.33	**Low**	7.05	5.8	17.74	21.074	16.014	25.10

6.4.4.1. Frequency variation in different rainy conditions using digital oscilloscope

It is been observed that with the change in the rain rate in the experiment there is a significant change of the frequency in the receiver end which is fairly related to the amount of rain falling on the laser link by the rain generated artificially. There is also the decline in the power as well, as the amount of loss is directly proportional to the increase of the rain rate, which is also similar as an account of the case of frequency.

6.4.4.2. Frequency profile at transmitter and receiver end

A. Frequency profile at transmitter end

As mentioned earlier the experiment is been conducted to find out an in-depth analysis of the attenuation of the frequency and power of laser modulated beam with a preset frequency passed through the artificially simulated rain, thus, to study the loss of the frequency of the laser the frequency from the transmitted side has been taken as a point of source and plays a vital role in comparison with the other frequencies which is collected at the receiver side. In transmitter side, it show that 21.074 KHz transmitted in **Fig 6.21**.

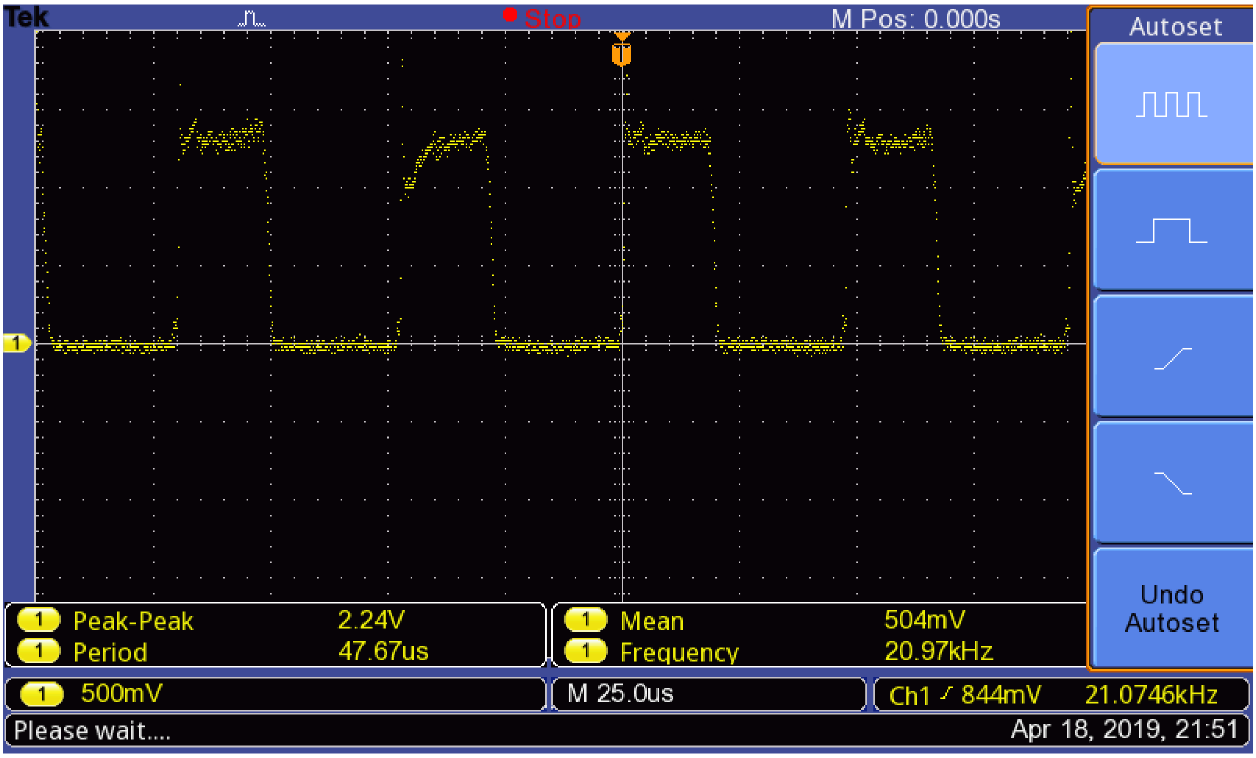


Fig.6.21: Frequency profile at transmitter end

B. Receiver side frequency(without rain)

In receiver side, it has been shown that 21.074 KHz received in **Fig.6.22**.

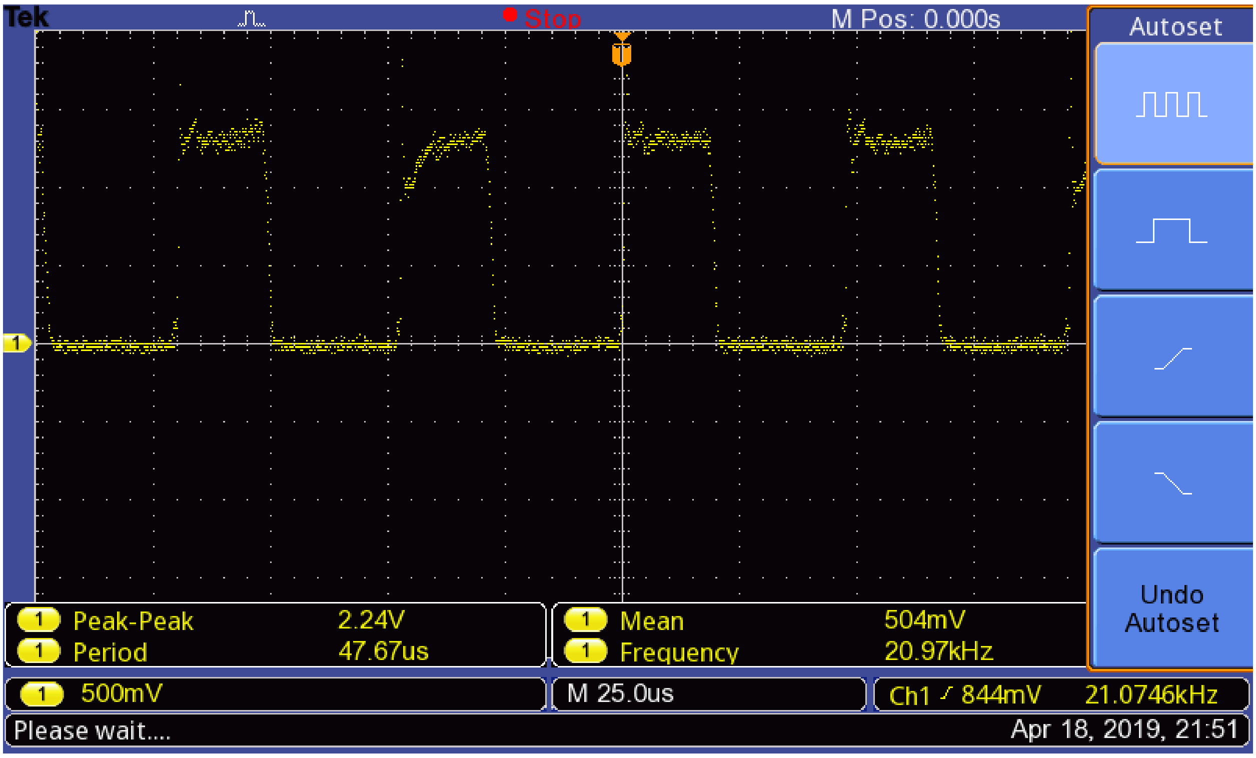


Fig 6.22: Receiver side frequency without rain

6.4.4.3. Receiver side frequency (light mode)

In this case the experiment is been conducted with help of ball valve which is used in the secondary water line system where the flow of water is been controlled as in result the water which is entered to the primary section of the rain water system is less, thus the rain rate is significantly less. The rain rate recorded is 15 mm/hr.

Fig.6.23shows data at the receiver side, where 21.074 KHz frequency becomes 16.014KHz frequency in this situation.

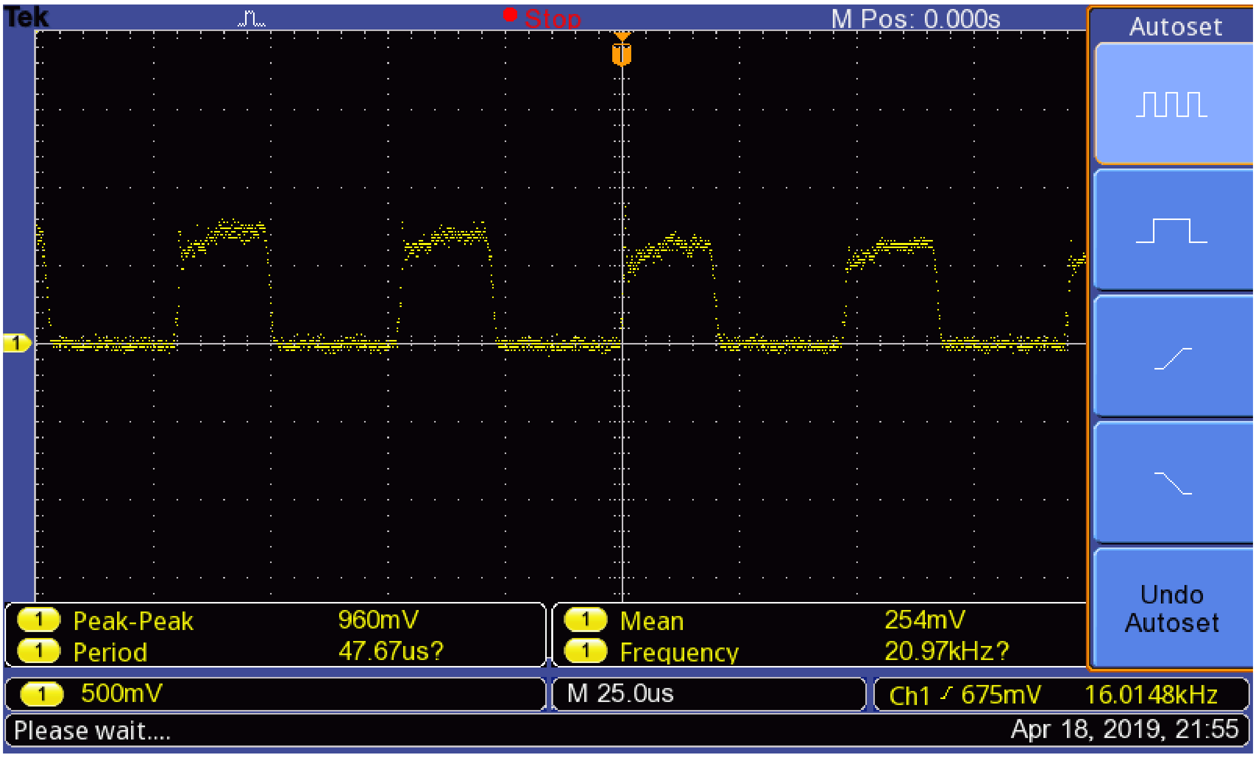


Fig.6.23: Receiver side frequency with rain rate 15mm/hr

6.4.4.4. Receiver side frequency (medium mode)

The amount of water is entering the instrument is further changed as the ball valve is released a bit where resulting in the increase of the amount of water in the primary water system, which increase the rain rate of the system, thus the rain rate increased to the point which was recorded to have rain rate 30mm/hr.

In receiver side, the 21.074 KHz frequency has been degraded to 14.891 KHz frequency in this situation. That has been shown in **Fig.6.24**.

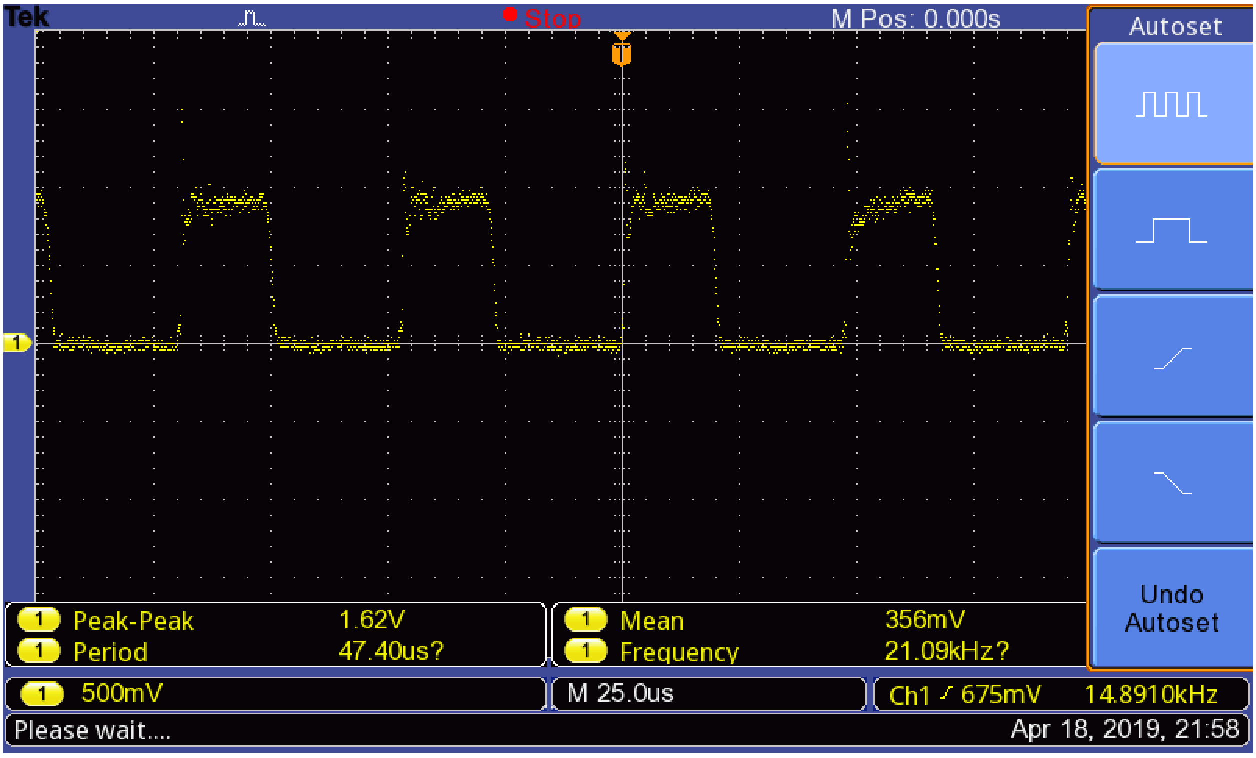


Fig 6.24: Receiver side frequency with rain rate 30mm/hr

6.4.4.5. Receiver side frequency (heavy mode)

In this case for the sake of the experimental purpose the ball valve is further released which increase the flow of the water thus increasing the rain rate, this case is being denoted as heavy mode as it depicts heavy rain shower in the natural condition. In this case the rain rate is measured to be 50mm/hr.

In receiver side, it is found that 21.074 KHz frequency changes to11.715 KHz frequency in this situation. That has been shown in **Fig. 6.25**

Fig.6.26 shows the graphical representation of the 808 nm laser experiment which is being conducted with the help of this laser

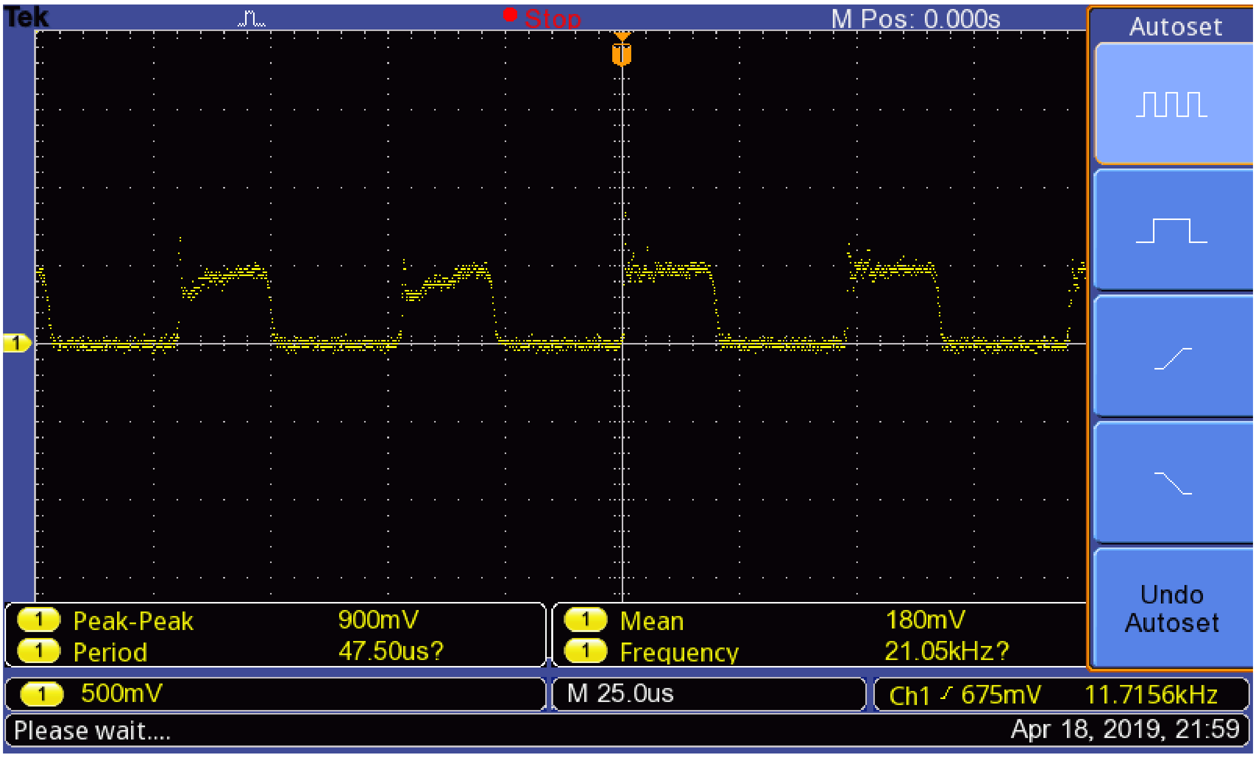


Fig.6.25: Receiver side frequency with rain rate 50mm/hr

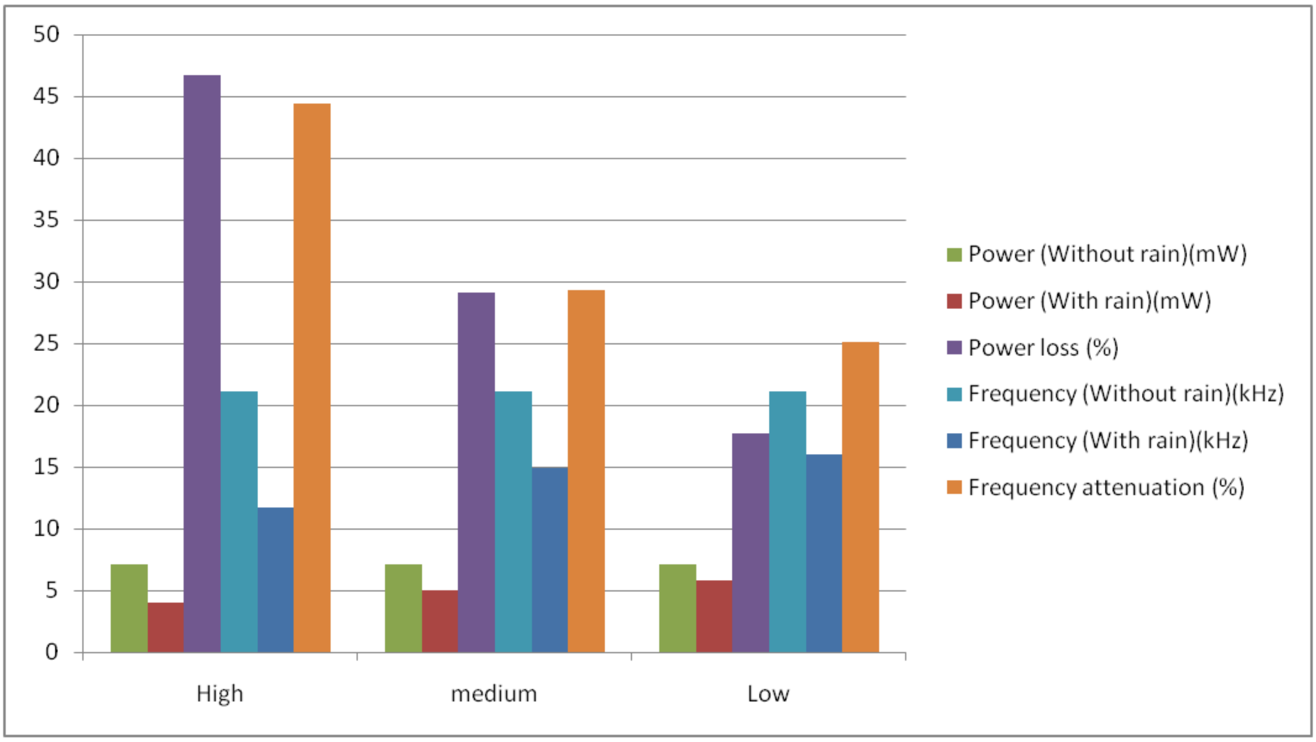


Fig. 6.26: Graphical representation of 808 nm laser experiment

6.4.5. Laser wavelength of 980nm

The 980nm laser is a not visible to the naked eye as the beam is infrared as it totally invisible. The laser is manufactured with the power of 400mW. As shown in the **Table 6.6:** below:

Table 6.6: Experimental result of rain simulation of 980nm laser

Sl No	**Wavelength(nm)**	**Distance (m)**	**Rain rate**	**Power (mW)**		Power loss (%)	**Frequency (kHz)**		Frequency attenuation (%)
				Without rain	**With rain**		**Without rain**	**With rain**	
1	980	11.33	**High**	4.5	3	33.34	20.398	11.629	42.99
		11.33	**medium**	4.5	3.4	24.50	20.398	14.542	28.79
		11.33	**Low**	4.5	4	11.12	20.398	18.871	7.48

6.4.5.1Frequency variation in different rainy conditions using digital oscilloscope

It is been observed that with the change in the rain rate in the experiment there is a significant change of the frequency in the receiver end which is fairly related to the amount of rain falling on the laser link by the rain generated artificially. There is also the decline in the power as well, as the amount of loss is directly proportional to the increase of the rain rate, which is also similar as an account of the case of frequency.

6.4.5.2. Frequency profile at transmitter and receiver end

A. Frequency profile at transmitter end

As mentioned earlier the experiment is been conducted to find out an in-depth analysis of the attenuation of the frequency and power of laser modulated beam with a preset frequency passed through the artificially simulated rain , thus to study the loss of the frequency of the laser the frequency from the transmitted side has been taken as a point of source and plays a vital role in comparison with the other frequencies which is collected at the receiver side. In transmitter side, it show that 20.398 KHz transmitted in **Fig.6.27**.

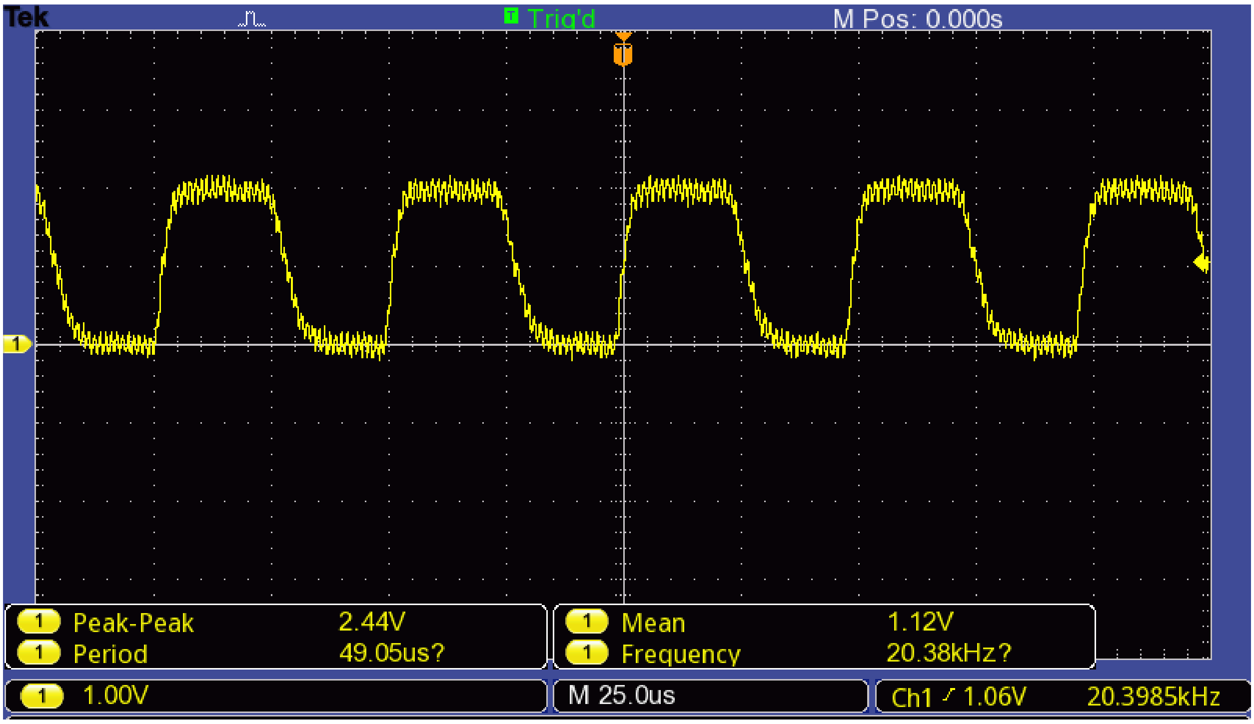


Fig 6.27: Frequency profile at transmitter end

B. Receiver side frequency (without rain)

In receiver side, it has been shown that 20.398 KHz received in **Fig .6.28.**

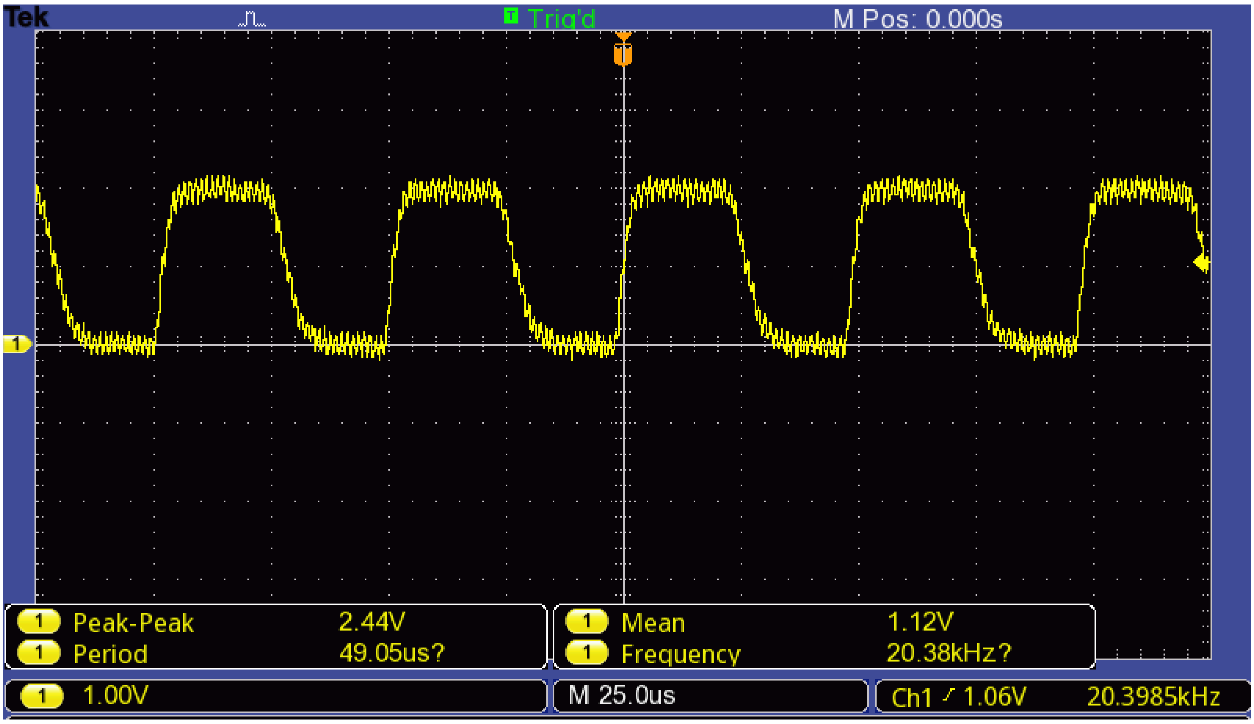


Fig.6.28: Receiver side frequency without rain

6.4.5.3. Receiver side frequency (light mode)

In this case the experiment is been conducted with help of ball valve which is used in the secondary water line system where the flow of water is been controlled as in result the water which is entered to the primary section of the rain water system is less, thus the rain rate is significantly less. The rain rate recorded is 15 mm/hr.

Fig. 6.29 shows data at the receiver side, where 20.398 KHz frequency becomes 18.871 KHz frequency in this situation.

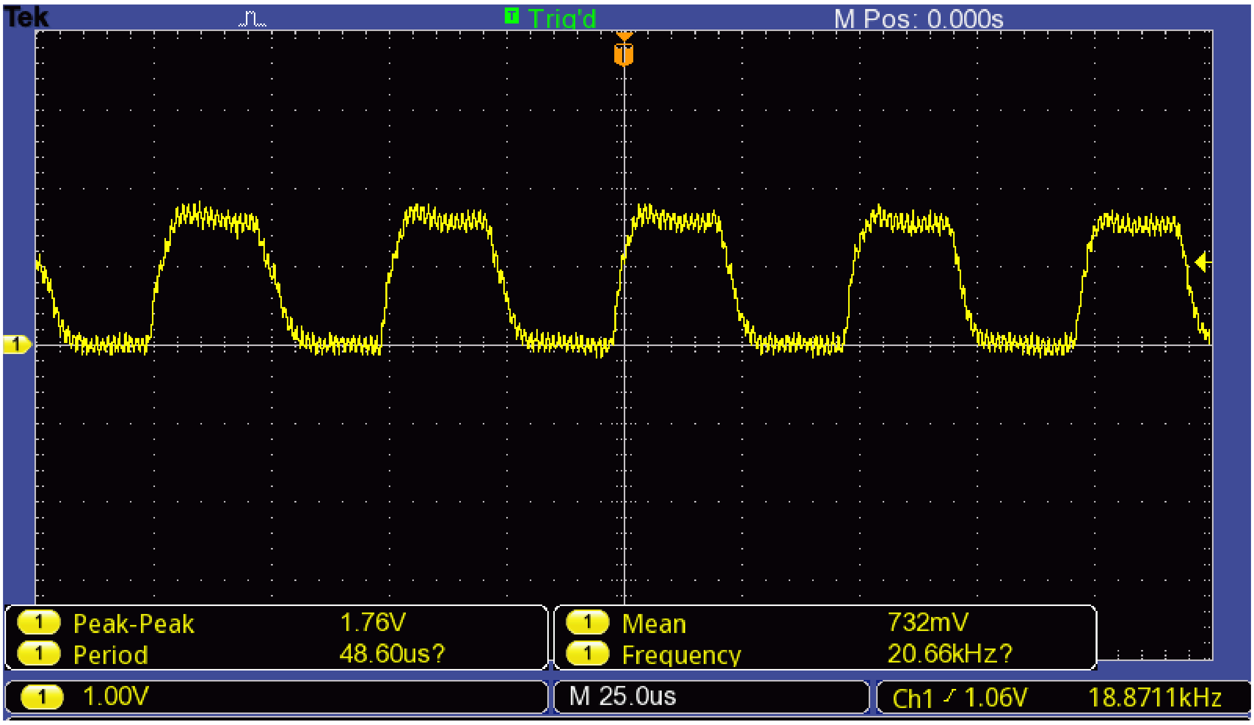


Fig.6.29: Receiver side frequency with rain rate 15mm/hr

6.4.5.4. Receiver side frequency (medium mode)

The amount of water is entering the instrument is further changed as the ball valve is released a bit where resulting in the increase of the amount of water in the primary water system, which increase the rain rate of the system, thus the rain rate increased to the point which was recorded to have rain rate 30mm/hr.

In receiver side, the 20.398 KHz frequency has been degraded to 14.542 KHz frequency in this situation. That has been shown in **Fig.6.30**.

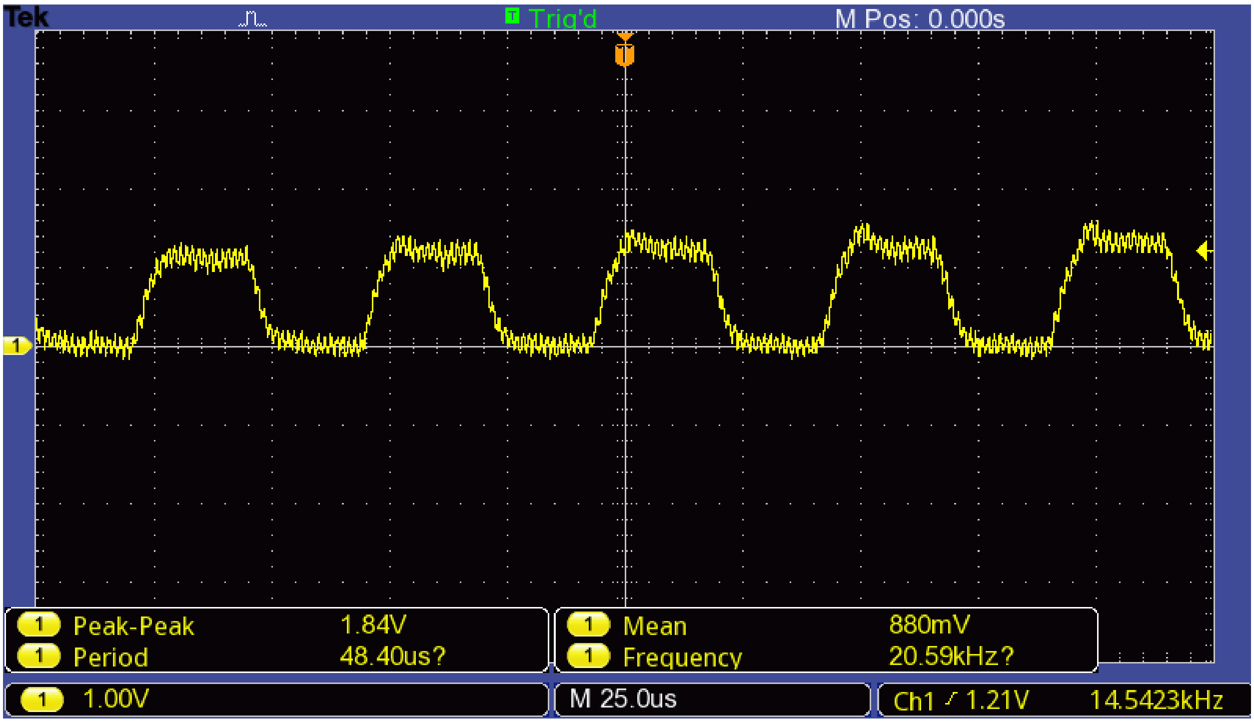


Fig.6.30: Receiver side frequency with rain rate 30mm/hr

6.4.5.5. Receiver side frequency (heavy mode)

In this case for the sake of the experimental purpose the ball valve is further released which increase the flow of the water thus increasing the rain rate, this case is being denoted as heavy mode as it depicts heavy rain shower in the natural condition. In this case the rain rate is measured to be 50mm/hr.

In receiver side, it is found that 20.398 KHz frequency changes to11.629 KHz frequency in this situation. That has been shown in **Fig. 6.31**

Fig. 6.32 shows the graphical representation of the 980 nm laser experiment

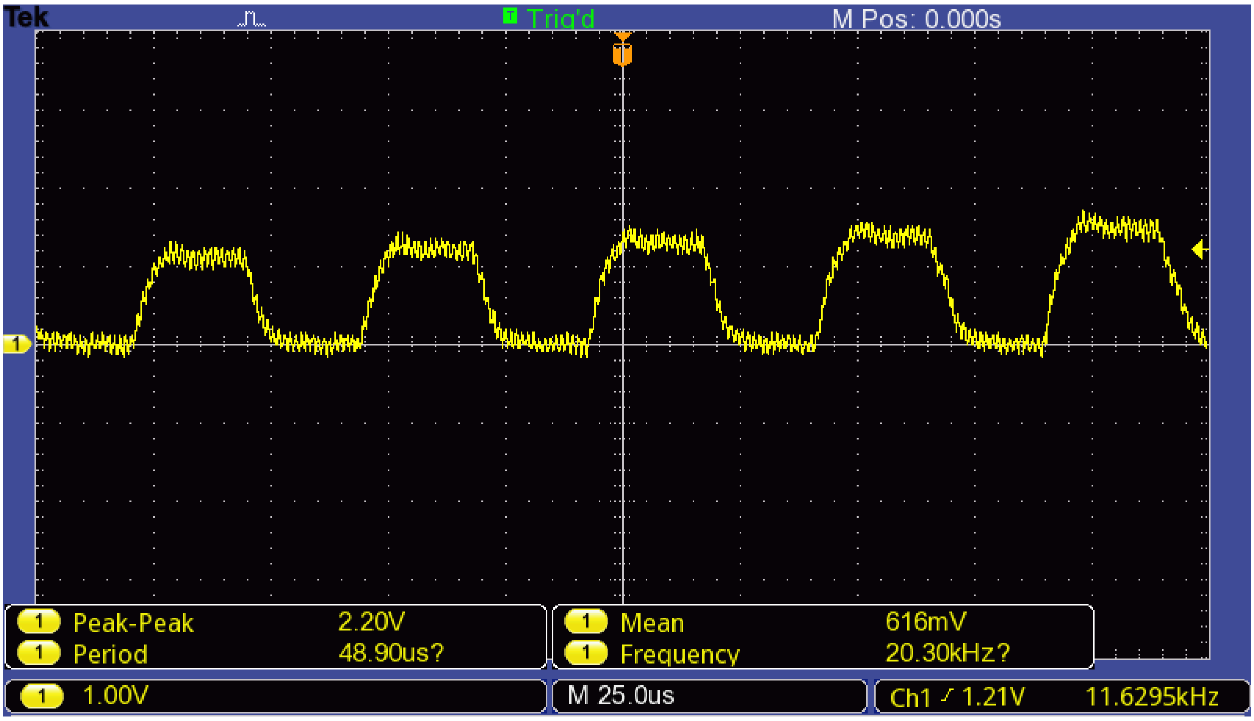


Fig.6.31: Receiver side frequency with rain rate 50mm/hr

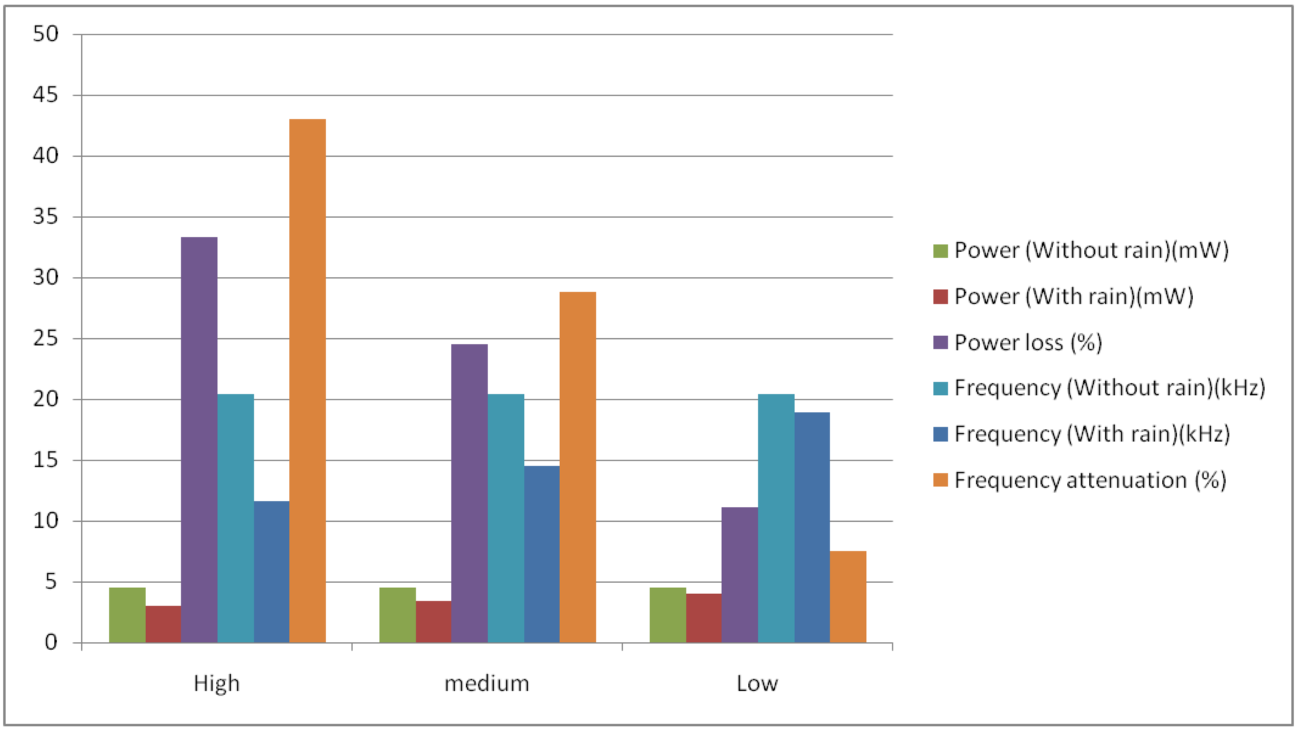


Fig.6.32: Graphical representation of 980 nm laser experiment

6.5.Conclusions

From the above results obtained from the help power meter and oscilloscopeat the receiver end, there is a significant amount of attenuation which is observed and collected. The frequencies which were collected at the receiver end do not match then frequencies collected at the transmitter end. There is a pattern which is also being observed in this experiment, the loss of frequencies are directly proportional to the increasing rain rate, and the loss of power is also significantly same. There is also a loss of power in the receiver end of the setup, which also proves that a laser power and laser modulated frequency is heavily related to the rain rates, as there are significant amount of information which was lost during the whole process.

The loss of the power and frequencies can be explained with the knowledge of extinction, which means the reduction in the intensity of a propagation laser beam, recollecting the data from the previous experiment done, and now applying the newly collected data from this experiment it is being observed that the visible laser attenuates less than the infrared lasers as the rate power and frequency of the lasers differs with its wavelength .

Chapter 7:STUDY OF POWER ATTENUATIONAT DIFFERENT CONDITIONS

7.1. Introduction

In the previouschapters,the study of the attenuation of the modulated frequency is done by the help of a VCO oscillatorwhere a preset frequency is set.Then the laser is modulated with the help of laser module and driver, as at a fair amount of distance a pin photodiode is used to receive the transmitted laser light. There are many possibilities where the received frequency may not be at an optimum single as there are many attenuation factors which can hamper the laser link.Some of the attenuation can be categorized as predictable attenuation and unpredictable attenuation. As there are many ways by which the experiments conducted in the previous chapters can have inaccurate results. The main problem of free space communication is atmospheric attenuation and geometric attenuation, as in the previous experiments the results showed that there is a significant large amount of loss occurred in the whole process.

But it is also seen that the frequencies obtained from the results,suggested that the frequency is dependent on the rain rate, more accurately it can be said that the attenuation of the frequency is dependent on the intensity of the rain.

But the results also shown that the frequency attenuation does not depend on the distance, the same rate of frequency is observed at 11.33 meter and also at 33.33 meter, which can be justified as the laser beam is modulated with the preset frequency and the photodiode used in this particular experiment is equally efficient to detect the transmitted signal without much problem. But the same thing is not observed with the case of power of the required laser used.

From the previous experiment conducted the power of 5 diverselasers with theirdifferent wavelengths has been showing a constant rate of decline with respect to distance, which was very odd to see the decline of power at an immense rate. Well this can occur for many reasons as the main reason is the atmospheric attenuation where the rain is also a major factor for the loss of energy as the pervious real time artificial rain simulation was conducted for that purpose only . With that there are other predictable attenuation such as geometric attenuation and molecular attenuation as mentioned in the earlier chapters. The other type of attenuation consists of turbulence, sunlight or any interference of artificial light.

The purpose of this experiment is also to determine if the modulation pose any change in power of the laser's power output with the variation of the distance, to have an accurate set of data for the calculations the whole experiment is done in closed dark room.

7.2. Experimental setup and method

The experiment is done inside a dark room with an option of illuminating the whole room via artificial light, this is used to setup the instruments in their proper manner and place with the option of creating a more controlled simulation of laser link. The whole experiment is done without the use of artificial rain simulator as the main intention is to capture the raw or untapped power of the laser. The whole setup is done with 5 different lasers with their respectable wavelengths. This is also done intentionally as to observe the characteristic nature of the individual laser with its attenuation pattern.

The whole experiment is conducted in the range of distance varying 0 meter to 11.33 meter, the varying of the distance is done to have a clearer view of the pattern of power attenuation. After various calculations in this experiment three different distance was considered which were at 0 meter then at 5 meter and then at 11.33meter.

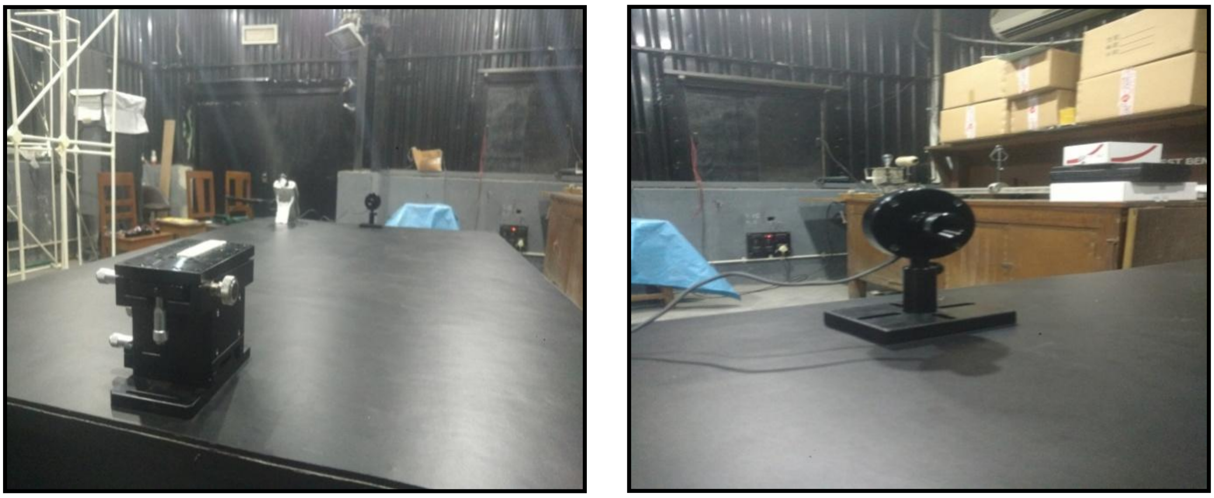
In this experiment the power meter is used at the receiver end to capture the laser beam, at a distance, which is varied at different time accordingly with the requirement of the proposed experiment.

At the transmitter end of the experiment where the laser is kept on a very sophisticated transition stage which is required to have an optimum percentage of laser beam entering the input of the power meter, this is done for two reasons to avoid which are geometrical loss and link margin. As the reducing of geometrical loss means the amount of laser beam entering the input of the power meter is maximized, which would help in successful collection of the required data. It would also help in the establishment of a stable laser link as would reduce the link margin.

The first set of experiment is done at a zero distance where the date for both modulated and non-modulated laser beam is taken. This is also done to have a base and optimum value of laser beam which is furthermore used as in the relation of acquiring the relationship of different laser power to its attenuated power.

The next set of set experiment is done at a distance of 5 meter which is chosen for the better understanding of the attenuation rate of power. As it is expected, the lasers of different wavelengths will each attenuate in their own different way.

The last set of experiment is done at the distance of 11.33 meter which is the furthest point of the dark room and there is also another reason why this distance was chosen,as in the previous experiments done aparticular 11.33 meter was taken into consideration. By using the same distance it will be easy to compare the two readings, so as to study the variation of the attenuation in case of outdoor and dark room as the **Fig. 7.1** shows the power meter and the translation stage.



(a) (b)

Fig. 7.1:(a) Translation stageand **(b)** Laser power meter

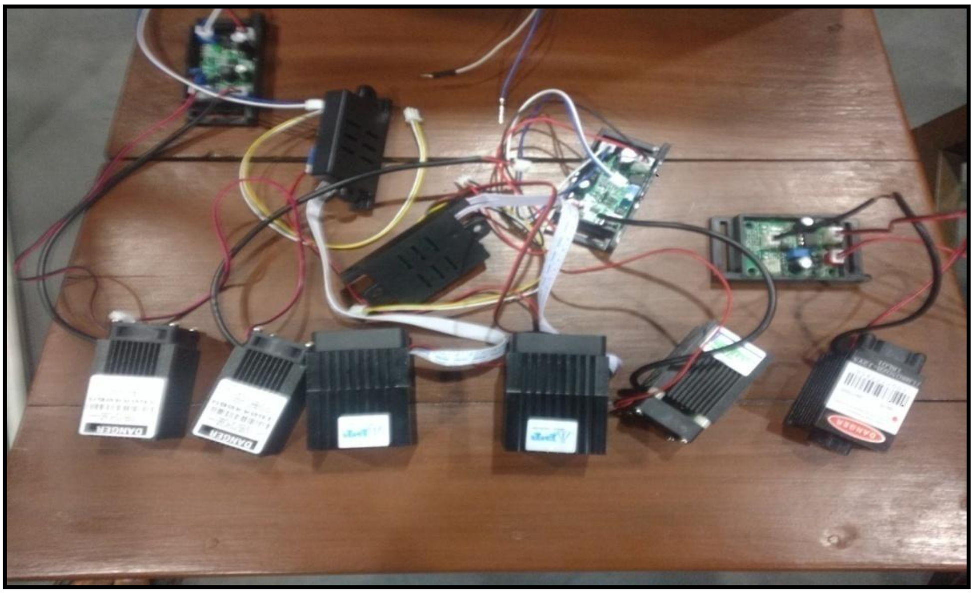


Fig. 7.2: Lasers with different wavelength

Fig. 7.3: Dark room setup

7.3. Experimental results

As discussed earlier in this chapter, the experiment is conducted with the help of laser power meter and 5 different lasers are used with their respected laser module and with the help of VCO oscillator. The experimental results are shown in **Table 7.1.**

Table 7.1: Experimental result of laser power attenuation at different distance

Sl No	**Wavelength (nm)**	**Distance(m)**	**Power(mW)**		**Power attenuation (%)**	
			With modulation	**Without modulation**	**With modulation**	**Without modulation**
1	450	0	230.59	357.19	-	-
		5	131.45	154.45	42.99	56.75
		11.33	86.74	158.62	62.38	55.59
2.	532	0	230.96	254.63	-	-
		5	164.87	180.18	28.61	29.23
		11.33	67.87	70.18	70.61	72.43
3.	638	0	250.23	336.41	-	-
		5	182.32	202.49	27.13	39.80
		11.33	50.22	70.54	79.93	79.03
4.	808	0	268.21	333.87	-	-
		5	148.98	192.78	44.45	42.25
		11.33	7.85	8.63	97.07	97.41
5.	980	0	157.87	300.25	-	-
		5	58.56	69.55	62.90	76.83
		11.33	9.45	11.23	94.01	96.25

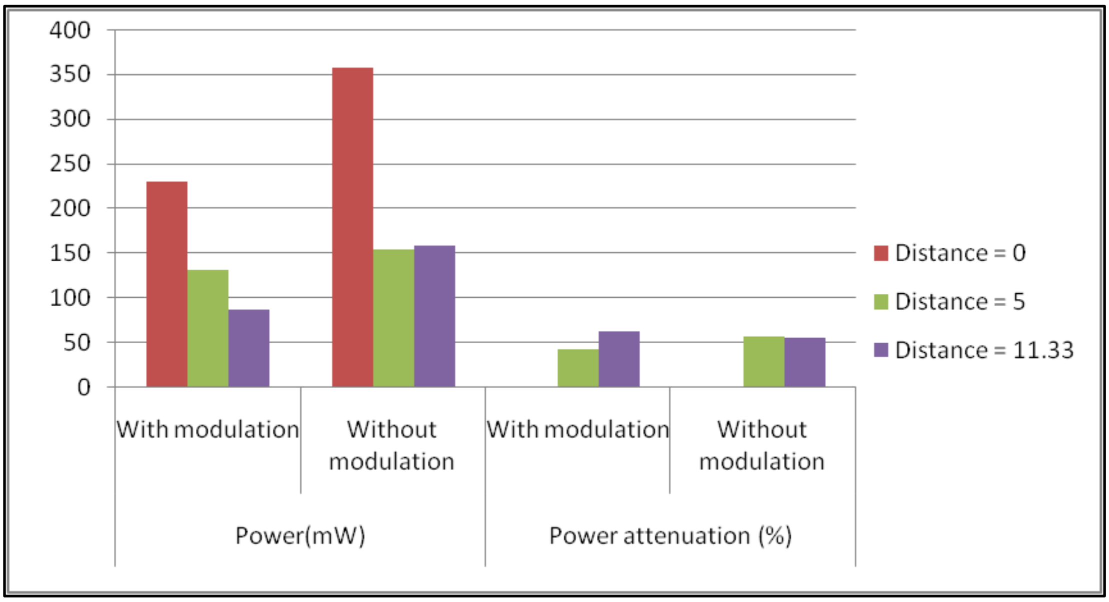


Fig. 7.4: The graphical representation of power and its attenuation in 450nm

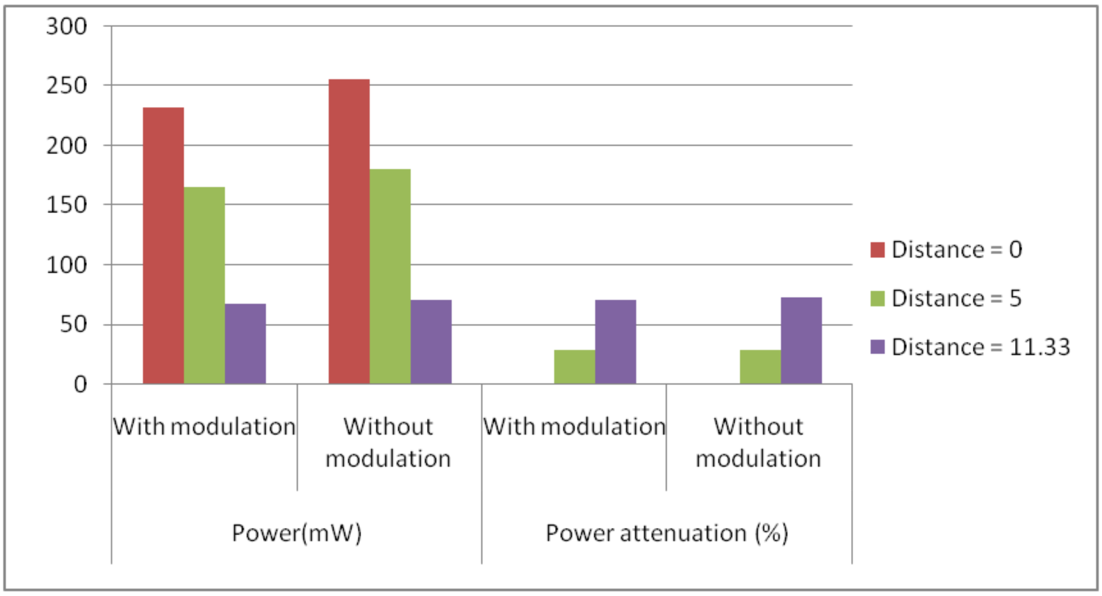


Fig. 7.5: The graphical representation of power and its attenuation in 532nm

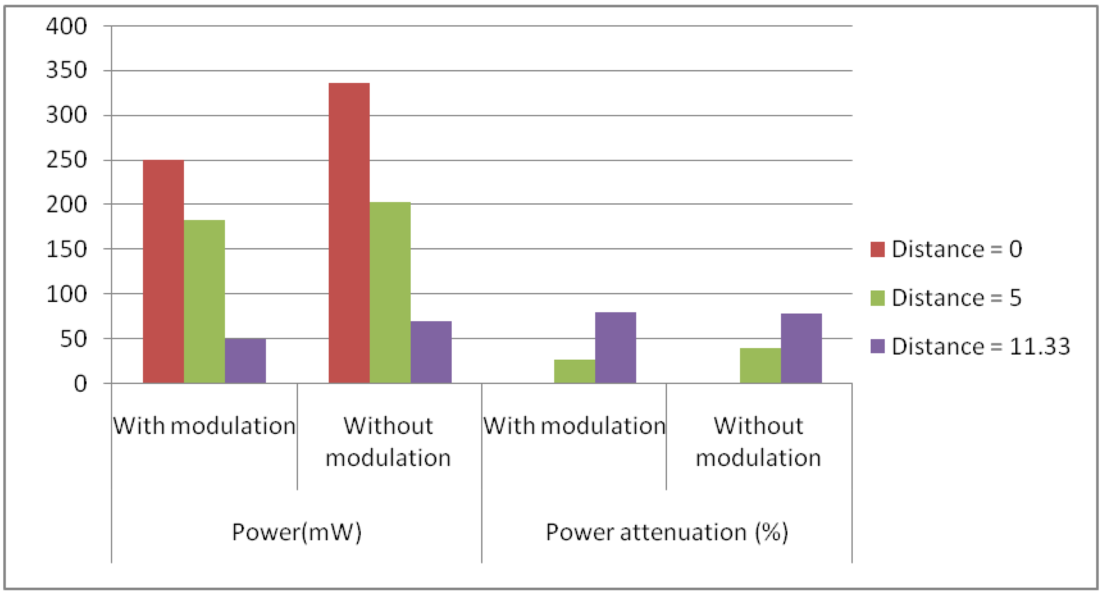


Fig.7.6: The graphical representation of power and its attenuation in 638nm

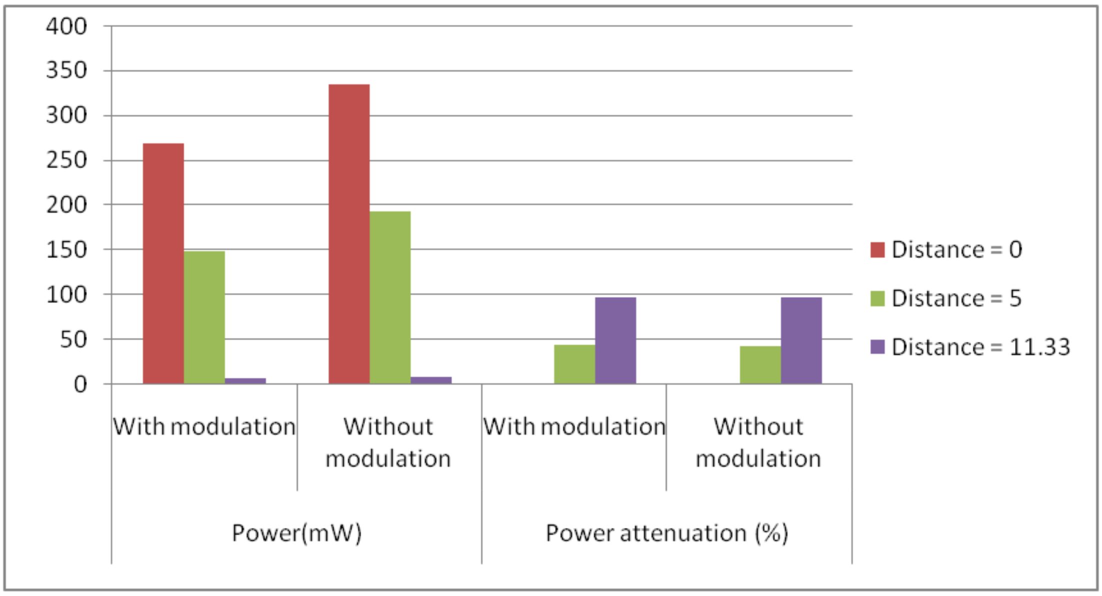


Fig. 7.7: The graphical representation of power and its attenuation in 808nm

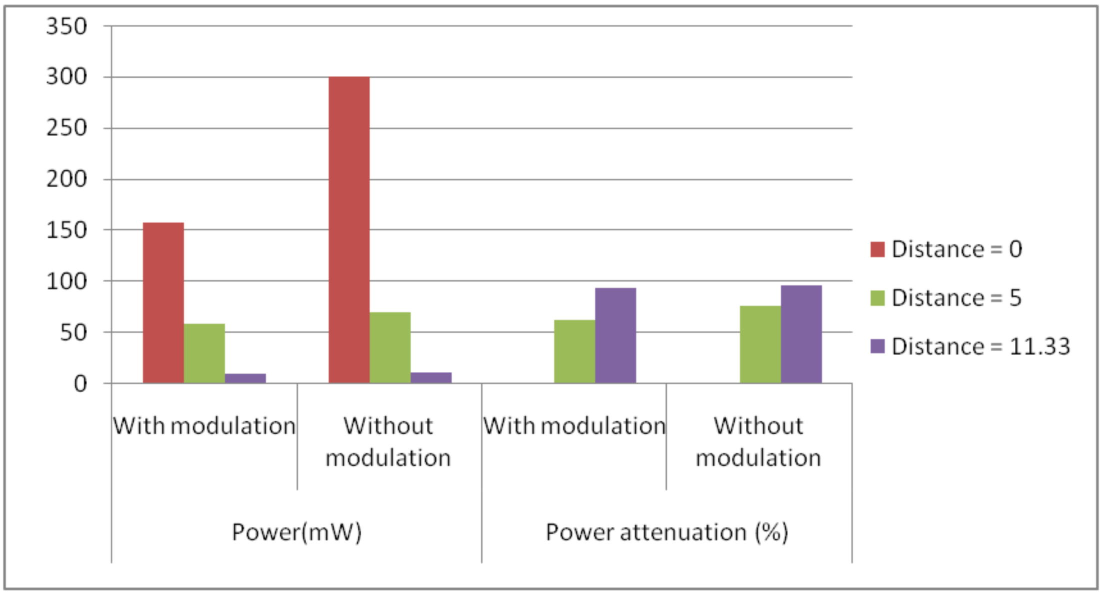


Fig. 7.8: The graphical representation of power and its attenuation in 980nm

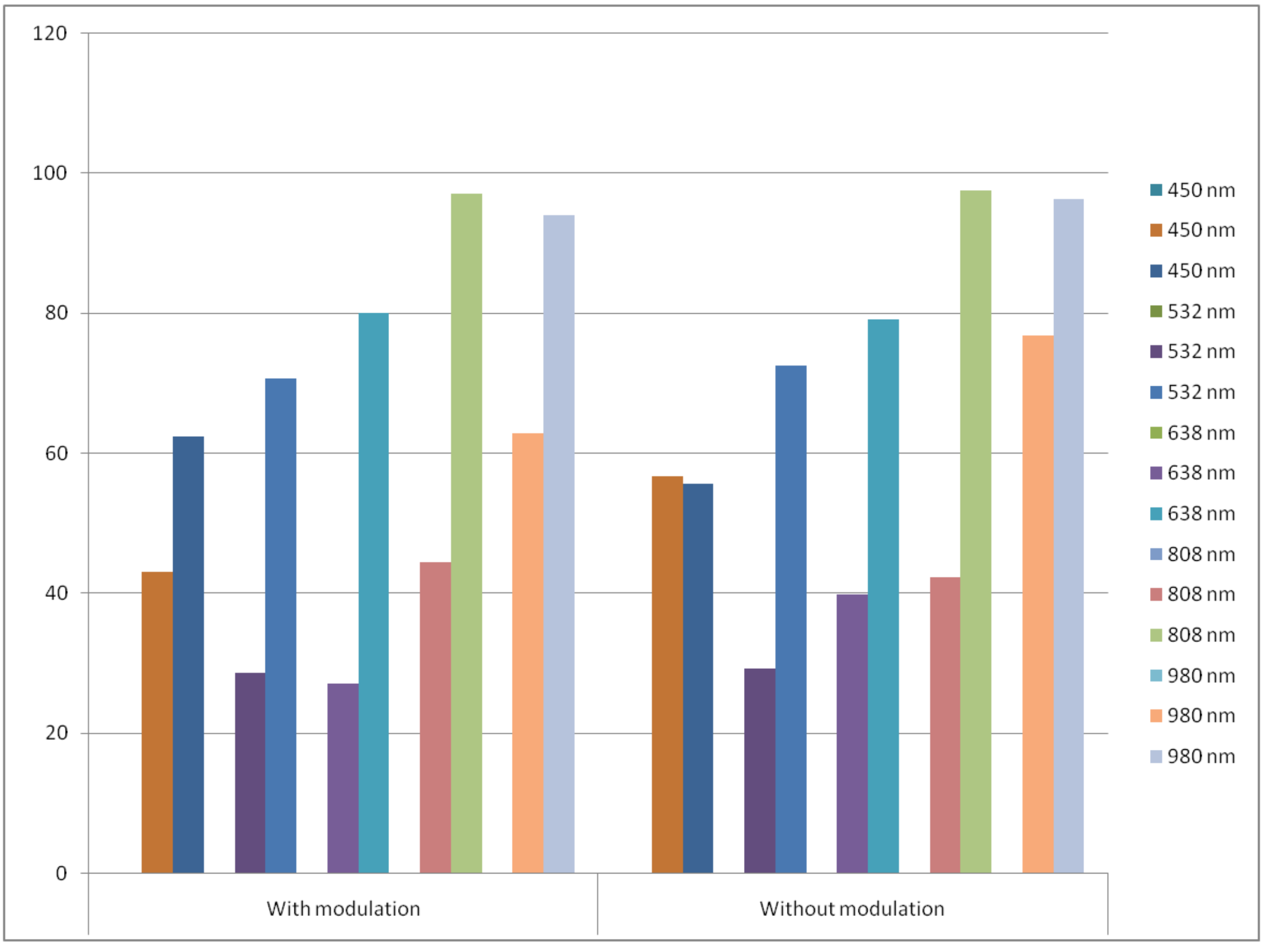


Fig. 7.9: The graphical representation of power and its attenuation of all lasers

Another comparison was done in this chapter, as in chapter 7 the whole experiment was done innormal outside condition and the laser beam attenuated in a specific manner . Again in this chapter a similar experiment was conducted with same set of lasers, by comparing the normal condition output with the dark room data it can be used to detect that any atmospheric conditions like scintillation, turbulence, solar background radiation etc , effects the beam in 11.33 meter or not. In the following **Table 7.2** depicts the difference of the two sets of data for comparison.

Table 7.2 : The difference of power attenuation in dark room with outside normal condition

Wavelength(nm)	Distance (meter)	Power received (mW)		Difference(mW)
		Dark room(indoor)	Outside (after 6.30pm)	
450	11.33	86.74	71.30	15.45
532	11.33	67.87	51	16.87
638	11.33	50.22	38.70	11.52
808	11.33	7.85	7.05	0.8
980	11.33	9.45	4.5	4.95

7.4. Conclusions

From the above results it is very obvious that the power of the laser is directly related with modulation of the laser beam, as each and every of laser output actually reduced significantly.

There is a reduction of power as the power meter of the laser was varied in distance and it is observed that the reduction of power is directly proportional with the increase in distance in the dark room.

As mentioned earlier the same experiment was conducted at a same distance which is 11.33 meter and the data was recorded, as in this chapter a similar type of experiment was conducted but in dark room. By comparing the data it was observed that the loss of power in normal open sky condition is much higher than the power recorded in dark room. This incident is explainable by the interfaces of sunlight and other sources of illumination which affects the laser beam. This type of attenuation is known as atmospheric attenuation which is discussed in previous chapters.

The above experimental result proves that unpredictable attenuation also plays an important role in the degradation of power, as the power collected from dark room setup was significantly higher as when the experiment was conducted outside.

The experimental results also showed that the pattern of power loss differs with laser's wavelength and laser module. It is also observed that the power of infrared laser degrade rapidly with the increase in distance than visible lasers.

CHAPTER 8: OVERALL CONCLUSIONS AND FUTURE SCOPE

8.1. Overall conclusions

In this thesis, a great emphasis was given on the topic of free space communication, as the working standard was discussed with its advantages and disadvantages of the entire system. The thesis also conveyed the modern ways by which this type of communication might exceed in comparison with other types of communication like RF communication.

The thesis also discussed the disadvantages of the free space optical communication, the main problem of free space optical communication is different types of attenuations, in atmospheric attenuation the rain attenuation of (special attenuation) is mainly discussed in this thesis.

In chapter 6 a free space communication was conducted with the help of VCO oscillator and laser module as it modulated the 808 nm DPSS laser diode. An artificial rain simulator was created and used to measure the drop of preset frequency and laser transmitted that the transmitter end and then power is received and measured by the help of a laser power meter and the frequency is received by using a photo detector. After conducting the whole experiment by varying the rain rate of the artificial simulator, it was observed that a significant amount of signal and power losses.

In chapter 7, a similar experiment was conducted by using 5 different DPSS lasers, and in this experiment a new artificial rain simulator was built to have a more realistic rain like feature. After the conduction of the experiment it was observed that all the lasers attenuated regardless of their wavelength, but some lasers attenuated less than others. It was deduced that the loss of power and frequency both depends on the rate of rain rate, and the attenuation also depends on the beam profile.

In chapter 8, another experiment was conducted by using same 5 DPSS lasers and same modulator, VCO oscillator and laser power meter. But in this particular experiment, it was conducted in dark room, to find out the power attenuation of each laser with modulation and without modulation. It was observed that when a DPSS lasers are modulated, the diode faces a power drop. But the percentage of power drop is not dependent on the wavelength but the module itself.Another comparison was made as in chapter 7 the whole experiment was conducted outside the lab under sky. Thus in chapter 8, the whole experiment was done in dark room and by using the same distance which is 11.33 meter a comparison of power loss was made. It was observed that there was a loss of power in each laser.

8.2. Future scope

Based on the earlier experiments the present study can be performed with the help of different components, thus observing that there is a loss of power and frequency in rain and at different atmospheric conditions. As these two parameters are very important in the progression of the free space communication, thus a lot of other experiments should be conducted to have more widely a in-depth knowledge in this field.

It is very important to overcome the attenuation problem as it holds a wide range of possibilities where it can help to improvise the scenario of the existing communication system in many ways.

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APPENDIX

Instrument / Components required for artificial rain simulation

1. IR Viewer

This instrument is used in this experiment. For this work, 450 nm, 532 nm, 638 nm, 808 nm and 980 nm DPSS lasers are used. 808 nm & 980 nm lasers are belonging to IR spectrum region, so that's why this wavelength is not visible in naked eye. Using this instrument, Laser alignment and safety IR viewers are ideal for alignment of infrared laser beam and optical components in near infrared systems can be operated. This instrument can be used also in photo processing, thermal imaging etc. Here, Abris-M 2000 model is used for this experiment. Fig 1 shows the IR viewer. Fig 2 shows the technical specification of IR Viewer.

Fig 1: IR Viewer

Technical Specification

Version	Abris-M 1X	Abris-M 2X
Spectral sensitivity	Abris-M 1300 (350-1300nm)	
	Abris-M 1700 (350-1700nm)	
	Abris-M 2000 (350-2000nm)	
Resolution (centre)	60 Lp/mm	60 Lp/mm
Field of view	40°	20°
Magnification	1X	2X
Objective lens	F1.4/26mm	F1.8/50mm
Focus	0.15m to inf	0.25m (0,15m)* to inf
Working distance of lens	12.5 (+/-0.2) mm	12.5 (+/-0.2) mm
Battery	1.5V, 1x "AAA" size	
Non-uniformity of screen	<20%	
Non-uniformity of response	<15%	
Distortion of image	<18%	
Battery life (continuous)	35 hours	
External power supply	DC 3V, 30 mA	
Weight	0.38kg	0.42kg
Dimensions	140x78x52 mm	145x78x52 mm
Temperature range	-10°C...40°C	
Tripod or handle connection	R"1/4"	
* with distance ring		

Lenses 1X (F1.4/26mm) and 2X (F2/50mm) are exchangeable.

Fig 2: Technical Specification of IR Viewer

2. Laser Power Meter with Sensor

This instrument is used for measuring the Laser power at different distance with the help of sensor and the value of power can be displayed in the meter. In this experiment, Ophir, (Vega) model is used. Fig . 3 shows the display unit of Laser power meter with sensor. There are some brilliant features of this instrument as follows:

- Compatible with all standard Ophir thermal, BeamTrack, pyroelectric and photodiode sensors
- Brilliant color large size TFT 320x240 display
- Compact handheld design with rubberized bumpers and optimized 2 position kickstand
- Choice of digital or analog needle display
- Illuminated keys for working in the dark
- Analog output
- Log every point at up to 4000Hz with pyro sensors
- Non volatile data storage up to 250,000 points
- Laser tuning screen and power and energy log
- USB and RS232 interfaces with StarLab and StarCom PC applications, LabVIEW driver and COM Object Interface (see pages 150-156)
- Soft keys and menu driven functions with on line help
- Many software features such as density, min/max, scaling etc.

Fig 3: Display Unit of Laser Power Meter and Sensor

3. Voltage Controlled Oscillator (VCO) Circuit

Voltage-Controlled Oscillator (VCO) Figure 4 shows the schematic diagram of the VCO. To ensure low system-power dissipation, it is desirable that the LPF consume little power. For example in an RC filter, this requirement dictates that a high-value R and a low-value C be used. However, the VCO input must not load down or modify the characteristics of the LPF. Because the VCO design shown in Figure 4 was an n-MOS input configuration having practically infinite input resistance, a great degree of freedom is allowed in selecting the LPF components. Fig 5 shows the electrical parameter of CD4046B VCO.

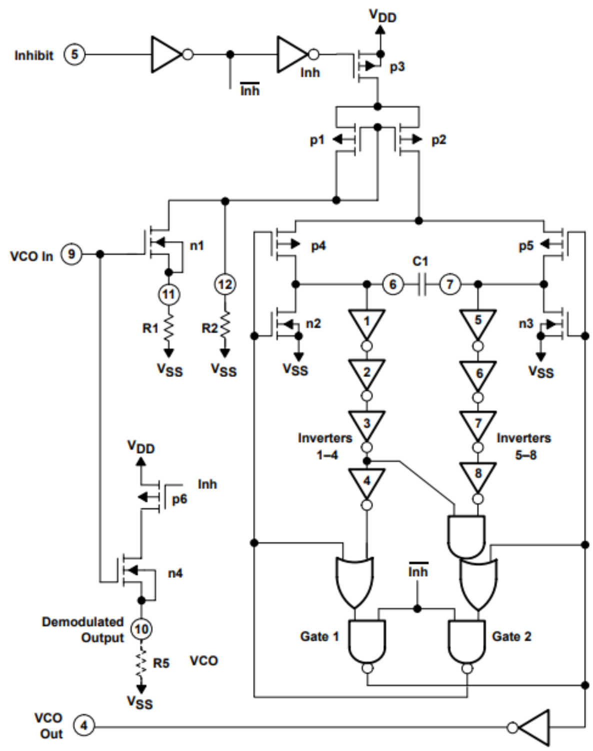

Fig 4: CD4046B VCO Section Schematic

Electrical Parameter of CD4046B VCO

VCO CHARACTERISTICS			TYPICAL VALUES AT $V_{DD} - V_{SS}$ = 10 V AND T_A = 25°C
Maximum frequency			1.2 MHz
Temperature stability			600 ppm/°C
Linearity (V_{VCO} in = 5 V ± 2.5 V)			1%
Center frequency			Programmable with R1 and C1
Frequency range			Programmable with R1, R2, and C2
Input resistance			10^{12}
Output voltage			10 Vp-p
Duty cycle			50%
Rise and fall times			50 ns
Output current capability	Logic 1: Drive at V_O	9.5 V	–1.8 mA
	Logic 0: Sink at V_O	0.5 V	2.6 mA
Demodulated output: Offset voltage (V_{VCO} in – V_{DEMOD} out) at 1 mA			1.5 V

Fig 5: Electrical Parameter of CD4046B VCO

Specification of the DPSS Lasers used in this present research work

All the DPSS laser used in this experiment share same specifications which is given below

Output Power	0.4W
Input Voltage	12VDC
Input Current	400mA
Working Temperature	-10℃~+30℃
TTL	>20KHz
Divergence	5mrad
Beam Diameter	6mm
Focusable	YES
LD808nm	0.5W
Lens Glass	YES
Dimensions	33*33*80mm
Working Life	>5000 Hours