Deanship of Graduate Studies

Al-Quds University

Sound speaker modulation of laser beam and its uses in different applications

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Thesis submitted in partial fulfillment of the requirements for the degree of master of Physics, Faculty of Graduate Studies,at Al-Quds University,Palestine.

2005

Deanship of Graduate Studies

College of Science, Physics Department

Al-Quds Uninversity

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Master Thesis submitted and accepted, date : 11 / 1 /2005

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Al-Quds University

2005

Declaration

I certify that this thesis submitted for the degree of Master of physics, is the result of my own research, except where otherwise acknowledged, and this thesis (or any of the same) has not been submitted for higher degree to any other university or institution.

Signed …………………..

Adnan Hassan Khalil Abu-tabikh

Date: 11 / 1 / 2005

Acknowledgements

I would like to express my sincere, special thanks and appreciation to my supervisors Dr. M. Abu-Taha and Dr. A. Leghrouz for their valuable guidance, continuous support, and encouragement. Thanks are also due to Mr. W. Keishi, the physics laboratory technician for his technical help.

I would like to thank my friends Yasser Serahni and Azzam Abu sabha for their help through numerous discussions.

Thanks also to jihad Naji, Samer Salamin and Azhare Salameen for photographing and typing this thesis.

Finally I offer special thanks to my father, mother, brothers, sisters, and to my wife Nihad B. Mahreeq for their encouragement, forbearance during the preparation of this thesis.

Abstract

Laser beam modulation is a process by which one of the beam parameters is changed in a controlled manner to trigger certain effect in a system or carry out an application requires transfer of information from one place to another. The applications that need laser beam modulations vary in purpose but mainly restricted to spectroscopic applications of all types. Wide range of applications using He-Ne laser were carried out employing speaker for vibration modulation. In This work the different modulation techniques are reviewed briefly only theoretically. Sound speaker technique is an intensity modulation technique which was found comparable to the rotating chopper amplitude modulation technique. Modulation techniques can differ according to the specified application. The simplest of all is the rotating wheel chopper, which modulate the beam amplitude with efficiency that reaches 100% easily. Magnetic and electric fields applied to optically active materials make a fast optical shutter. Certain types of lasers namely self –mode-locked Ti: Sapphire lasers allow polarization dependant modulation. Piezoelectric transducers (PZT) can be used in conjunction with an acousto-optic cell placed outside laser cavity for amplitude modulation. Contrary when the PZT tube is used intracavity to vibrate one of the laser mirrors the system is frequency modulated. The chosen modulation method depends on the type of application. The very simple method achieved by gluing a mirror to the diaphragm of an ordinary miniature speaker. The technique allows many of the applications that depend on laser absorption coincidence to be performed by a He-Ne laser enhancing by that range of applications in which it can be used and avoiding the complications and expenses needed for sophisticated equipment. Sound speaker modulation was found efficient and comparable to mechanical chopper modulation. The method is sensitive enough to determine minute changes in index of refraction or transparent material thickness change and suitable for emission monitor. Modulation using vibration with a speaker also can be noisy if high amplitude modulation used. Other methods might generate window noise or spatial beam instabilities. The system is composed of three main parts: He-Ne laser, the modulating unit and the detecting circuit. He-Ne laser beam is incident on a plane mirror glued to the diapharm of a speaker. The plane mirror will vibrate at the same speaker's frequency. The reflected laser light is allowed to pass through the sample of the interest before it falls on a photoelectric transistor (type BPX 381) that converts the modulated beam energy into an electric current which is then amplified and fed into a phase sensitive detector for further processing. Many experiments were performed with this method and results obtained with very good signal to noise ratios ~ more than 50 in most tests. 1% adulteration of natural orange juice was easily detectable and even better value 0.5 % is detected for brine concentration. The system shows a good ability to detect changes of index of refraction as small as 0.008 and thickness change of 0.25 mm. Odors and smoke release monitor under atmospheric conditions was found successful.

الملخص

إن عملية تضمين الليزر، (Laser Modulation) هي عملية يتم فيها تحميل الأشعة الضوئية (أشعة الليزر) بالمعلومات والأوامر، (موجات صوتية مثل موسيقى مثلا)، ونقلها من مكان إلى أخر عن طريق التحكم بخصائص وعناصر الموجات الضوئية المختلفة من طول الموجة، (Wavelength) أو اتساع الموجة، (Wave amplitude) أو التردد، (Frequency) أو شدة الإضاءة،(Light Intensity)؛ مثل تغير تردد الموجة وتحميلها موجة ذات تردد أقل. المصدر الضوئي المستخدم في هذا العمل هو"الهيليوم– نيون" ليزر،( ) He-Ne Laser وذلك لان هذا النوع من الليزر شائع الاستخدام بسبب توفره في المختبرات العلمية وقلة تكلفته.

في هذا البحث، تم استعراض الطرق المختلفة المستخدمة في عمليات تحميل المعلومات ونقلها من مكان إلى أخر، بشكل نظري واستعراض بعض استخداماتها.

إن التقنية المستخدمة في هذا العمل، هي تقنية يتم فيها تضمين شعاع الليزر بالموجات الصوتية باستخدام اهتزاز بوق السماعة المثبت عليه مرآة صغيرة مستوية. وقد تم فحص هذا النظام عن طريق مقارنته مع طرق أخرى مستخدمة في تضمين الأشعة بموجة و التحكم بالتردد، مثل القاطع ألدوراني (Mechanical Chopper)، وقد وجد أن كفاءته قد بلغت حوالي 100 %.

لقد وجد بأن هذه التقنية فعالة وحساسة بشكل كاف ودقيق لتحديد التغيرات الدقيقة في تركيب المواد، وقياس معامل الانكسار لمواد ومحاليل مختلفة التراكيز، وقياس سمك المواد، والكشف عن الروائح، و الغازات المنطلقة من بعض المواد بشكل طبيعي. يتولد أثناء عملية تضمين الليزر المعلومات عن طريق الاهتزاز ونقلها بعض التشويش و الإزعاج، وخاصة عند اتساع الموجات بشكل عالٍ (High amplitude) ، كما هو الحال في طرق التحميل الأخرى، وما ينتج من تشويش وعدم استقرار.

إن النظامِ ِّ َ المستخدم في هذا العمل يتكون من ثلاث وحدات و أجزاء رئيسة هي :–

أولا: المصدر الضوئي : "هيليوم – نيون" ليزر بطول موجي 632 نانوميتر.

ثانيا: وحدة التحميل و التحويل وهي دائرة الكترونية تم تصميمها.

ثالثا: وحدة التقاط الضوء المضمن المنعكس عن المرآة المثبتة في منتصف سطح السماعة.

وتتلخص الطريقة في أن الشعاع الضوئي الساقط من المصدر على المراة المستوية الصغيرة المثبتة في منتصف سطح السماعة التي تهتز بنفس تردد الموجات الصوتية المدخلة عليها، تتغير شدته نتيجة الاهتزاز، ومن ثم ينعكس هذا الشعاع عن المرآة المستوية نحو الخلية الضوئية الذي يعمل على تحويل الطاقة الضوئية المحملة إلى تيار كهربائي، الذي يتم تضخيمه بوساطة دائرة كهر بائية ثم تنتقل إلى جهاز حساس، (Phase sensitive detector) ومن ثم معالجتها.

لقد أجريت العديد من التجارب و التطبيقات العملية بهذه التقنية، وكانت النتائج لهذه التجارب جيدة جدا، كما أن هذا النظام يستطيع تمييز الغش في العصير الطبيعي بنسبة 1%، كما يستطيع التميز بين تركيز محلول ملحي بنسبة 0.5 %. ويبدي هذا النظام قابلية جيدة لتحديد تغيرات في معامل الانكسار قد تصل إلى اقل من 0.008 ،وقدرته في الكشف عن السمك قد تصل إلى 0.25 ملم. وقد أمكن باستخدام هذا النظام الكشف عن الدخان و الروائح و الغازات المنبعثة من بعض المواد، تحت الظروف الجوية العادية بشكل جيد وناجح مما يؤهله للاستخدام التقني في شتى مناحي الحياة.

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Chapter One

Introduction

1.1- Historical background

The signal or information or message as sounds or others can't be sent or transfer with traveling wave, because the traveling wave has the important property that it transports energy and momentum (Grawford, 1968). To send message or information from one place to another you need to modulate the wave that means to change the amplitude, frequency, velocity, wavelength, the phase of the wave that called amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM) etc. (Graford, 1968). In each type of modulation, the intended parameter is changed while the rest of parameters are kept unchanged, for example: in amplitude modulation the amplitude of the signal is changed while the other wave characteristics are unchanged, in the frequency modulation the frequency is changed, but the other parameters unchanged and in phase modulation the phase of the carrier was changed. The information that will be sent by an optical wave is coded in the intensity, amplitude, frequency or phase of the wave, and then is decoded by the detection system (Jasprit, 1995). In 1980, the light wave communication came of the age. The light have a dual nature; i.e. in some cases light acts like a wave (electromagnetic wave) and in others it acts like a particle. The polarization refers to the direction of the electric field in an electromagnetic wave, so a wave whose electric field is oscillating in the same direction is said to be polarized in that direction. The advent of the laser and the increasing use of lasers in a wide variety of applications led to a demand for devices that can modulate a beam of light (Wilson and Hawkes 1983). As it is well known that laser light is polarized. Laser system is mostly useful when operated in a stabilized single mode. The output of a laser, the laser beam, is usually pictured as a continuous beam having constant power, but for laser communications, the beam can be changed or modulated in a controlled manner. This modulation can be in the form of amplitude modulation (AM) which changes the strength or power of the beam, or frequency modulation (FM), which changes the frequency, or color of the beam, modulation adds information to the beam, such information can be carried by the beam and transmitted to a distant location, where it can be extracted and used. This can be a cheived using many techniques; for example the Acousto- optic, Kerr, and Faraday effects.

The polarizer is an optical device whose input is natural light and the output is some form of polarized light as the wire-guide polarizer, birfringent polarizer that was produced in 1828 by the Scottish physicist William Nicol (Zajic, 1987), Polaroid, which was invented by Edwin H. Lund is the first dichroic sheet polarizer like wire guide which known as Polaroid J-sheet in 1928 (Graford, 1968 and Zajic, 1987).

When a plane polarized wave propagates in some materials as quartz, sodium chloride, sodium nitrite, the plane of polarization is rotated, and the amount of rotation depends or proportional to the material thickness, this effect has been discovered by Arago in 1811 and known as optical activity (Nussbaum and Philips 1976). This effect was explained by Fresenal in 1825 (Zajic 1987).

The modulator is a device that change the irradiant or direction of light passing through it (Wilson and Hawkes 1983). There are several general types of optical modulators that will be covered briefly in chapter two:-

1- The birefringence modulator which is a device that modulates the polarization of light at high frequency, like a modulated quarter wave plate.

2- Photo elastic effect, In 1816 Brewster discovered that normal isotropic substances could be converted to anisotropic substances by mechanical stress (Zagic, 1987). The photo elastic modulator contains an optical part (block) that is typically an isotropic block of fused silica.

3- Magneto-optic effect (Faraday Effect): The Faraday or magneto-optic effect was one of the earliest indications of the interrelationship between electromagnetism and light (Zajic, 1987). Michael Faraday in 1845 found that when a beam of plane polarized light passes through a substance or material subjected to a magnetic field, so the emergent light is found to remain linearly polarized, but with some rotation (Wilson and Hawkes 1983**).**

4- Electro-Optic effect: In 1883, kundt and Röntgen working independently and in different countries simultaneously discovered that an applied electric field induced birefringence in quartz. In 1893, Pockels published a general theory of this effect (Nussbaum and Philips 1976).

5- The Kerr modulator; Kerr effect was discovered by the Scottish physicist Kerr in 1875 (Zagic, 1987) and (Frank, 1996). When an isotropic material is placed in an electric field, it becomes birefringent with optic axis parallel to the induced electric field (Fank, 1996).

6- The Pockel modulator: Pockel's effect is named after the German physicist Friedrich Carl Alwin Pockels (1865-1913) (Zajic, 1987). Pockels effect was another type of electro-optic effect that was discovered in 1893 long before the discovering of the laser and (Frank, 1996).

7- Acousto-optic devices are used in laser equipment for electronic control of the intensity and position of the laser beam. Acousto-optic interaction occurs in all optical mediums when an acoustic wave and a laser beam are present in the medium. In this technique, the angular deflection is proportional to the acoustic frequency. Acousto-optic effect is three dimensional diffraction effect (Lipson et. all 1995).

These techniques available in different laser wavelengths range. In these types or techniques, the refractive index and other optical characteristics of a medium are changed by the application of a field force like electrical, magnetic, and mechanical or an acoustical and this modify the phase or irradiance of the light beam that propagates through the medium.

The system used in this work is able to modulate laser light by vibrating a plane mirror glued to a speaker. The basis of this modulation is intensity modulation.

1.2- Thesis objectives:

This work is intended to use vibration modulation of a laser beam which can be applied to many experimental applications. Modulation was achieved by vibrating a plane mirror that was fixed on a speaker diaphram. The source of vibration on the speaker is a square signal wave from a generator.

This technique is used for the first time as optical modulator in these set of experiments as will be explained in chapter three. This technique worked successfully in the frequency range (10–1600) Hz, but the largest output signal was at 17.5 Hz. Consequently, after testing the system, the effects of several mediums on transferring the information by the modulated laser beam are listed in table 4.1. A new vibration modulation of laser beam by sound speaker and the effect of some mediums as water vapor, smoke and material thickness are studied. This technique is used in several applications successfully. For more information about modulation of light beam, the reader may refer to the following refrences, "(Crawford, 1968),(Wilson & Hawkes, 1983), (Frank, 1992), (Meyer, 1997), (Nussbanm & Phillips, 1976), (Zajic, 1987), and (Pedrotti, 1996)".

1.3- Method:-

An experimental investigation was performed using a He-Ne laser source at optical wavelength λ = 6328 Å. This work employs a He-Ne laser because it is popular, simple and manufactured in large quantities at low cost and with proper operation that can provide thousands of hours of useful service. The laser beam incident on a small plane mirror that was fixed on a sound speaker diaphram as shown in fig.(3.1) chapter three. The speaker vibrates giving a squar signal from an audio generator, the reflected beam allowed to pass through a sample and to fall on a photo electric diode (BPX 381) after being focussed. This usefull optical unit is linked to an amplification circuit for further processing of the signal.

1.4-Chapter description

This thesis contains six chapters, the contents are briefly given as follows:-

- Chapter one: **"Introduction"**: This chapter introduces the modulation definition and brief study of modulation types, the historical background to optical modulation, and explains the experiment procedure and discusses the aims of this work.
- Chapter two: **" modulation types and the optical modulators":** Explains the several types of modulation as amplitude modulation (AM), frequency modulation (FM), phase modulation (PM), position modulation, wavelength modulation (WM), and time modulation (TM), and brief review of some optical modulators as, optical activity modulator, magneto-optic modulator, electro optic modulator includes: Kerr and Pockel modulators, photo elastic modulators and Faraday modulators.
- Chapter three**:" experimental system and circuitry construction":** This chapter explains the experimental procedure of the system, its components and discusses the construction of the translational circuit and system testing.

- Chapter four: **"experimental data"**: This chapter deals with the vibration modulation applications using the laser beam and briefly describes the experimental procedures and the results obtained.
- Chapter five: **"Discussion and Conclusion":** results are analyzed and main conclusions are discussed.

Chapter Two

Modulation technique and optical modulators

2.1-Introduction:-

This chapter deals with modulation techniques used in different types of applications. Optical modulations are of special interest to the subject of this thesis and will be reviewed with some details. Understanding of optical modulation techniques requires corresponding of light beam properties on which these modulators employ the effect.

2.2- Modulation definition:-

Modulation is a process that combines a signal containing the desired information with some characteristics of a signal "carrier wave" so that the information or a group of information can be delivered through certain transmission media over distance. The characteristics that varied include its amplitude, frequency and phase corresponding to amplitude modulation (AM), frequency modulation (FM) and phase modulation (PM) (Zorkoczy, p. 1982). In modulation, one or more parameters of the carrier wave modified proportional to the signal information strength and in such away the modified parameter is a function of time (Wilson and Hawakes, 1989). There is a limit to the highest frequency used to allow the use of certain desirable wave transmission properties in the specific media. In order to achieve a clear and noiseless modulation, the high frequency "carrier wave" to be modulated must be stable and constant prior to modulation process. The modulator is a device by which imposes the required changes on the irradiance or direction of light passing through it, such as quartz, KDP (Potassium dihydrogen phosphate, mechanical choppers and shutters, passive, magneto-optic, electro-optic and acoustic- optic modulators. In these types, the refractive index and other medium parameters are changed by the field effect, i.e., electrical, magnetic, strain stress and mechanical (acoustical) stress (Wilson and Hawkes, 1983).

2.3- Modulation schemes:-

Many different techniques are used to transfer information to the appropriate wave parameter such as amplitude, irradiance, frequency, etc. These techniques may be divided into two main schemes:-

I- **Analog scheme:**

In this type, the primary signals, which were taken to be a time varying electrical voltage continuously, varied the appropriate wave parameter. The time relation is one to one between the original signal amplitude and the magnitude of the parameter (iprocess begins (Wilson and Hawkes, 1989)). The wave parameters, such as amplitude, irradiance, frequency and phase are not suitable for modulation at optical frequencies, because the main difficulties arise in signal demodulation, since detectors respond only to the irradiance of the radiation falling on it.

II- **Digital scheme**:

In digital scheme the information is coded into a series of pulses that temporal position are fixed with quantized amplitude (Wilson and Hawkes, 1989, & Simon, 1983, & Bissell and Chapman, 1997). This scheme is called two levels binary which are zero and one, i.e. the pulse amplitude has only one of the two levels, so one is refer or may be represented by the presence of a pulse of greater than predetermined amplitude and zero state by the absence of a pulse (Lionel, 1998). The great advantage of a digital system over an analog one is its relative freedom from noise or distortion (Wilson and Hawkes, 1989). In 1939, the english inventor Alec H. Reeves developed the pulse code modulation which was considered the most important form of pulse modulation because it can be used to transmit information over long distances with hardly any interference or distortion.

2.4- Modulation Techniques:-

There are a number of different physical effects involved in modulation. An external influence (mechanical force, a magnetic or electric field) can be applied on the optical medium, changing the manner in which it transmits light (Zajic 1987). The optical beam to be modulated is characterized by its amplitude, frequency, or wavelength and phase, all of these parameters can be modulated to code information as amplitude modulation, frequency and phase modulation (Jasprit, S. 1995).

This chapter deals with the optical modulators and modulation techniques.

2.5- Modulation Techniques:-

Modulation is a technique of modifying signals or waves in a known way. It is used to communicate information. The signals or waves can be represented as sinusoidal wave which can be written in mathematical form (Singh and Jasprit 1995) as:

$$S(t) = A \cos (2\pi f t + \phi), \qquad (2.1)$$

where A is the peak amplitude, f is the signal frequency and ϕ is the phase of the signal. The information can be sent by modulating one or more of these measurable quantities and changeable properties of the sinusoidal wave and then detecting these changes by the demodulators. The signal that is modulated is called the signal carrier or waves carrier because it carries the information from one place to another. Fields or signals modulated in these ways are called amplitude modulated; frequency modulated, and phase modulated waves (Stremler, 1990). In fact, since electromagnetic fields are vector fields, then the polarization of a wave can be made to communicate information through modulation.

However, polarization modulation is only normally used for special purpose as the polarization state of a wave can easily be distorted during free space transmission by effects like unwanted reflection from buildings. The polarization state of a field moving along a guide or a fiber can also be altered by bends or imperfections in the fiber guide.

There are several modulation techniques; each of them changes one of the properties of the basic signal.

2.5.1– Amplitude Modulation:-

This technique changes the amplitude of the crest of the carrier wave (Senior, 1992). The main advantage of this technique is that it is easy to produce such signals and also to detect them. Amplitude modulation produces a wave, i.e. amplitude modulated of the form:-

$S_m(t) = A_m \cos(2\pi ft + \phi)$ (2.2)

Where A_m is the amplitude of the modulation carrier, and

$A_m = A\{1 + m(t)\}$, where m is the index of modulation. The amplitude modulation carrier contains three terms:- the un-modulated carrier term, an upper side band with frequency (fc + f_m), and a lower sideband with frequency ($f_c - f_m$), where the f_c is the carrier frequency (un-modulated carrier) and f_m is the frequency of modulation carrier. The change in the amplitude of the carrier wave crest the greater is the degree of the modulation and this degree is expressed as a percentage of the un-modulated carrier amplitude (Singh 1995). Amplitude modulation technique has two major disadvantages, the first is that the speed of changing amplitude is limited by bandwidth of the line, and the second is that small amplitude changes need very reliable detection.

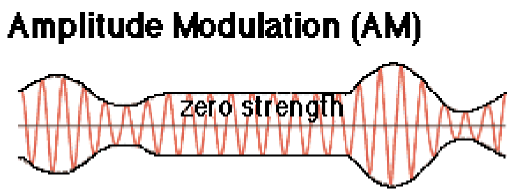


Fig. (2. 1). Amplitude modulation of carrier wave.

To modulate the amplitude of a laser beam i.e. introduce regular change in the amplitude at certain frequency, the beam is interrupted with a mechanical chopper rotating at certain frequency as shown in figure (2.2).

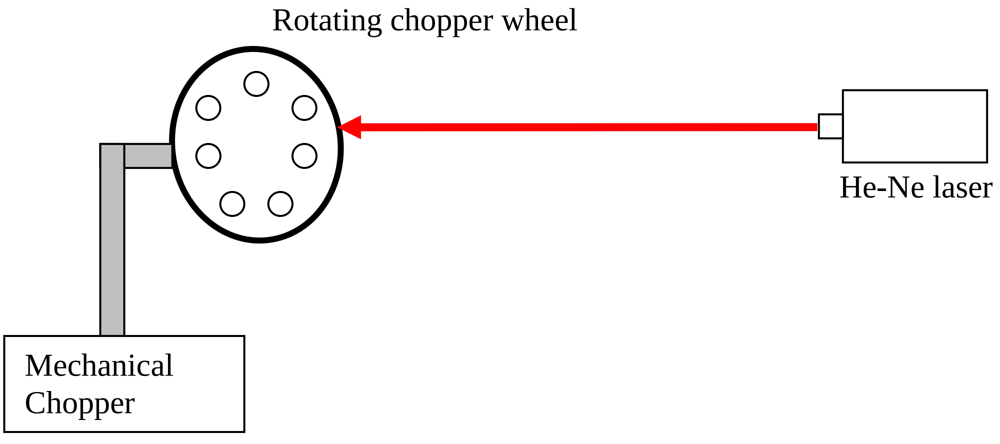


Fig.(2.2): A schematic diagram of mechanical chopper.

The beam then passes through the holes of blade of the chopper wheel at certain intervals of time depending on the speed of the rotating wheel. The emerging beam in this case will have the full zero or beam amplitude. Amplitude modulation can be used for studying the propagation and focusing of the high power laser beam without distortion. In fig. 2.2 if a photocell connected to an oscilloscope is placed behind the rotating disk, a recorded signal as shown in fig. 2.3 is obtained.

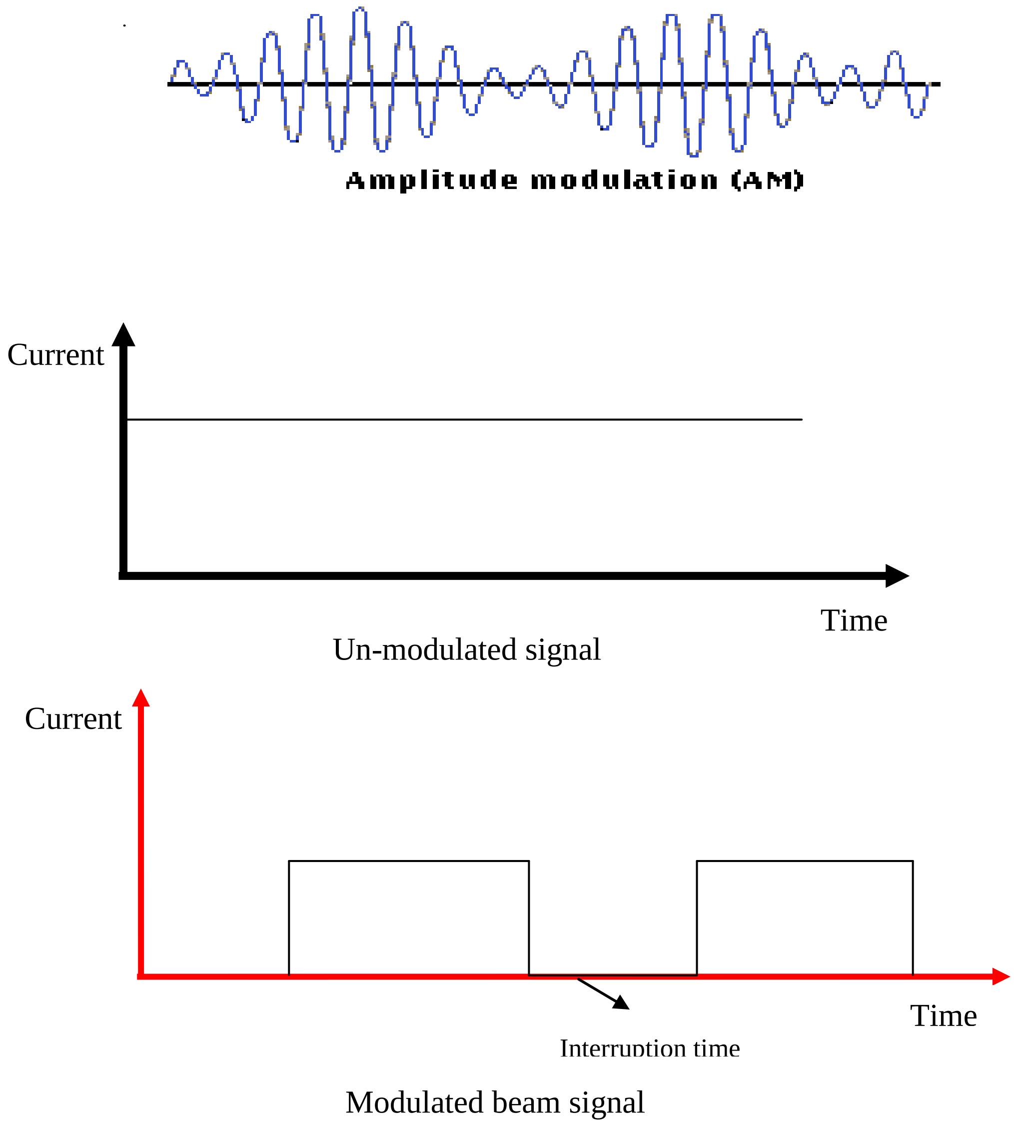


Fig.(2.3) Photocell signal of modulated and un-modulated He-Ne laser beam.

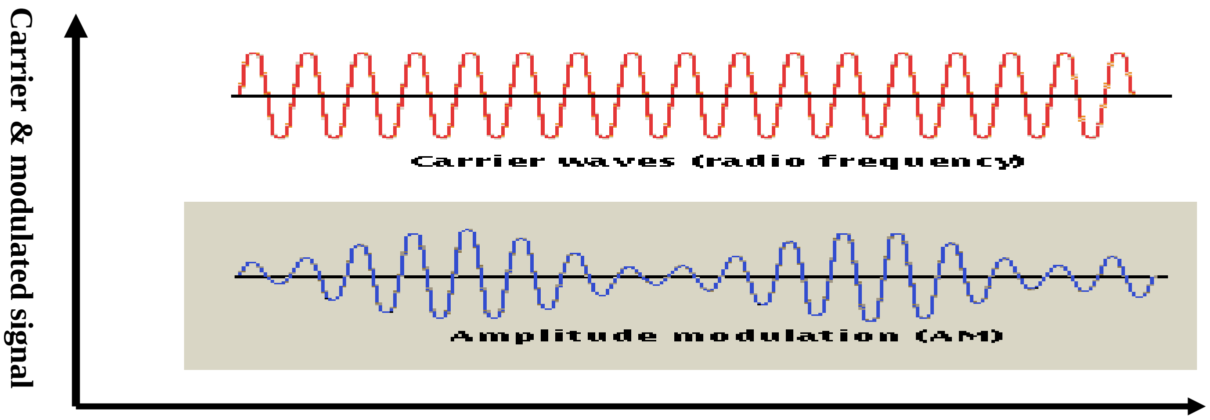


Fig. (2. 4): A schematic of the amplitude modulation carrier signal.

2.5.2- Wavelength modulation:-

The wavelength of a monochromatic wave is the distance between two consecutive wave peaks as in transverse wave, while in longitudinal wave, it is the distance from compression to compression or rarefraction to rarefraction (See fig.(2.5)).

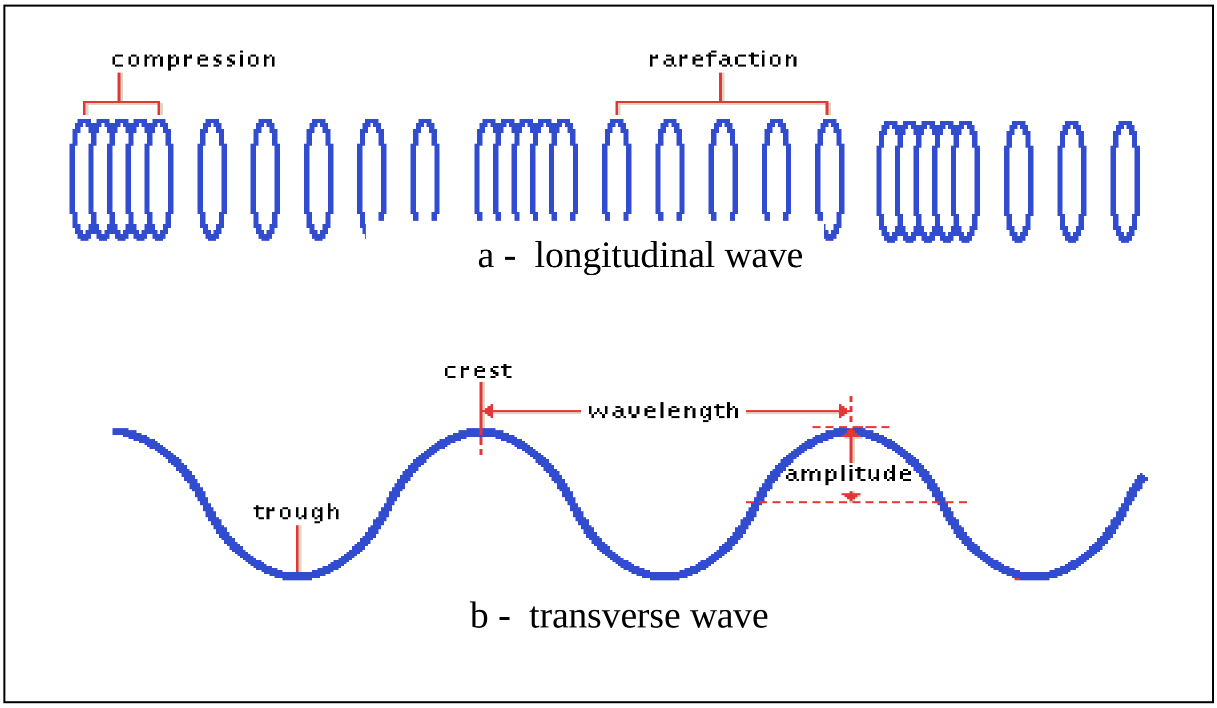


Fig. (2. 5): The wavelength of (a) longitudinal and (b) transverse waves (after Encarta Encycloedia, 2003)

The frequency corresponds to the number of wavelengths that pass by a certain point in space in a given time. In this technique the wavelength of the monochromatic wave is changed, then frquency of the wave follow according to the relation:

$f = c / \lambda$, where f : frquency, c: wave speed, and λ: wavelength.

Wavelength modulation techniques are characterized by a modulation frequency that is much smaller than the half-width of the absorption profile. They can be described in principle by the same formalism as frequency modulation (Schilt, 2003). Both wavelengths techniques differ by the amount of frequency deviation in the modulation process.

The amplitude of the wave remain unchanged, so the amount of frequency deviation in frequency modulation is generally between (1-10) KHz (Rothman, Rinsland, Goldman, Massie, Edwards, Juckes and Brown, 1998), while λ less than few parts of million or few gigahertz. The wavelength change in a frequency modulated signal is extremly difficult to detect by optical spectrometer; but at wavelength modulation the frequency deviation is generally on the order of parts per thousands hertz, and the associated wavelength change can be detected by spectrometers. This type of modulation does not require the use of stabilized laser, since wavelength deviation is long compared with the drift of many lasers. This techinque is usefull for digital communications, and it is not widely employed in most practical applications because of the relative difficulty of constructing an efficient and fast device. Wavelength modulation is widly used for gas detection (Schilt, Luc and Robert, 2003).

2.5.3- Frequency Modulation:-

In this technique, the frequency of a sinusoidal wave is varied, while the amplitude and the phase of the input signal or wave unchanged. The un-modulated frequency of a frequency modulated signal is called its center (carrier) frequency (Klingenfuss, 1998). When a modulation signal is applied, the frequency modulation transmitter's frequency will swing above or below the center (carrier) frequency according to the modulation signal as shown in Fig. 2.6.

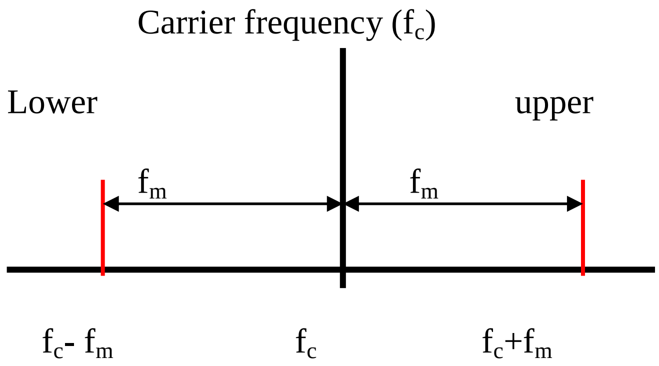


Fig. (2.6): The frequency modulation (FM) components and their deviation (redrawn from, Singh).

The amount of the "swing" in the transmitter's frequency in any direction below or above the center frequency is called deviation, so the total frequency space occupied by a frequency modulation signal is twice its deviation. The frequency-modulated wave has frequency components at the carrier frequency and at sidebands, spaced above and below the carrier (center) frequency. If a frequency modulated beam goes through a sample that attenuates one sideband more than the other does, the balance is broken and the result is an amplitude modulation. Frequency modulation has several advantages over the amplitude modulation, some of them are: - frequency modulation has greater freedom from interference and static signal to noise ratio in a frequency modulation is much higher than of an amplitude modulation. Finally, frequency modulation can be operated in the very high frequency bands. In fig. 2.3 if a photocell connected to an oscilloscope is replaced behind the rotating disk a recorded signal is as shown in fig. 2.7.

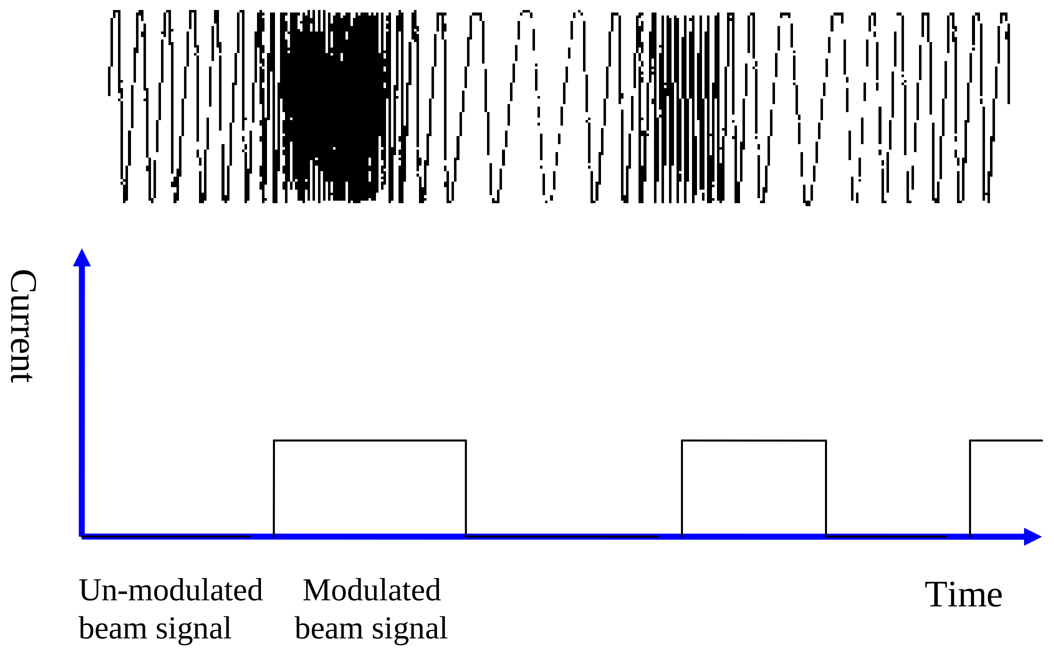


Fig.(2.7) Photo cell signal of modulated and un-modulated He-Ne laser beam.

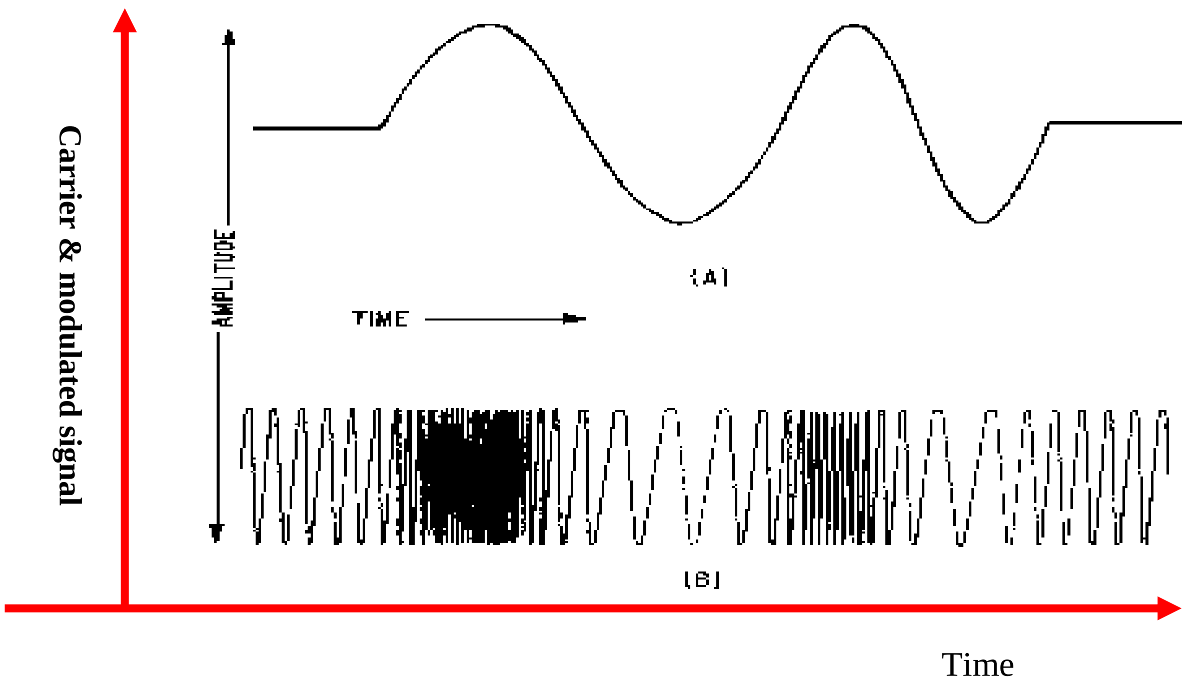
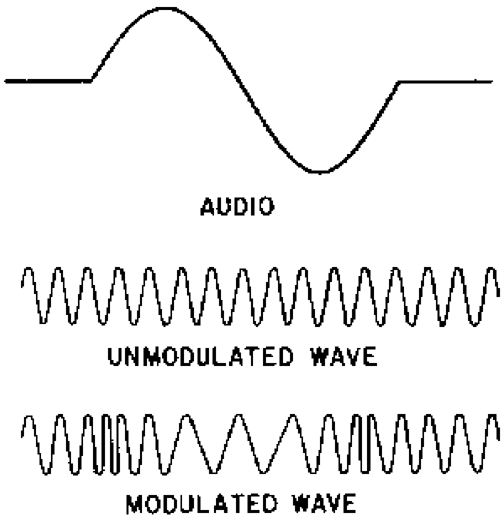


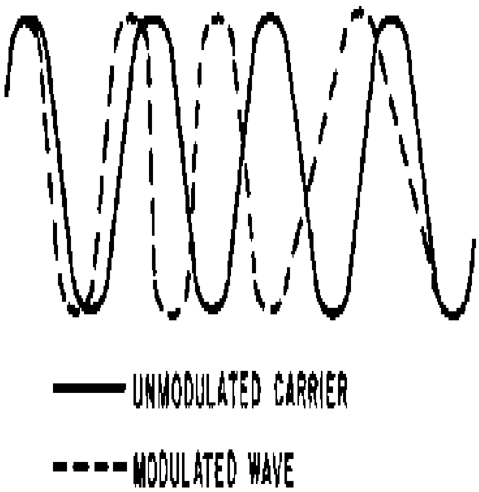
Fig. (2. 8): A schematic of the frequency modulated carrier signal.

2.5.4- Phase Modulation:-

Phase modulation is similar to frequency modulation i.e. when the instantaneous phase of a carrier is varied, the instantaneous frequency changes as well. Contrary when the instantaneous frequency is varied, the instantaneous phase changes. It cannot be said that phase modulation and frequency modulation are exactly equivalent, since the relationship between phase and frequency variations is not linear. The amount of phase shift is proportional to the amplitude and frequency of the modulating signal. In this type, the phase of the highly stable carrier wave is modulated by an analog signal or switched between two more states according to digital signal. In analog phase modulation, the phase of the signal wave varies in a continuous manner. When the instantaneous data input has positive polarity, the carrier phase shift in one direction, when the instantaneous data input waveform has negative polarity, the carrier phase shifts in the opposite direction. At all time moment, the phase angle is directly proportional to signal amplitude polarity.

In digital phase modulation, the carrier shifts abruptly, rather than continuously back and forth. In optical system, the frequency and phase stabilized lasers are required as sources for the carrier wave and as a local oscillator for reference. At visible and near-infrared laser, phase modulation seldom used except recently in the development of coherent optical communication system using stabilized diode lasers. However, at far-infrared wavelength light sources as "CO_2 lasers" can be stabilized relatively easily and phase modulation is more common in laser communication system.





(a) (b)

Fig. (2.9) phase modulation of signal wave, and un-modulated signal.

2.2.3.1- Optical activity:-

Optical activity is a certain material which has ability to rotate the plane of polarization of light through it. (Lipson et all 1995). These materials include both solids, for example, quartz and sugar, and liquids like turpentine and sugar in solution. (Frank 1996), some of these materials produce a clockwise rotation (dextrorotatory) of the electric field, and others produce a counterclockwise rotation (levorotatory).The optical activity is measured by using two linear polarizer's originally set for extinction. When a certain thickness of optically active material is put or inserted in active cell between analyzer and polarizer, then the extinction exists because the electric vector of the light is rotated by the optically active medium this idea is explained in fig. (2.10)

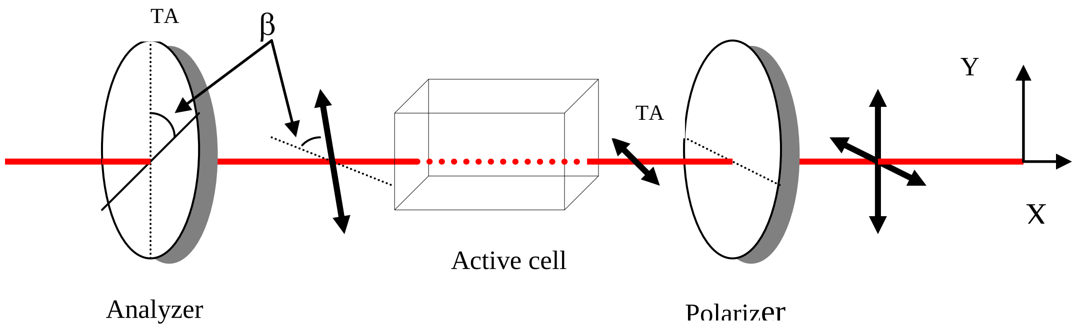


Fig. (2.10): The measurement of optical activity by the angle β required to reestablish extinction with active material in the cell.

The French physicist Arago was the first who observed the optical activity in 1811. He discovered that the plane of vibration of a beam of linear light rotates as it propagates along the optical axis of quartz plate. This is shown in fig. (2.11). (Zajic 1987)

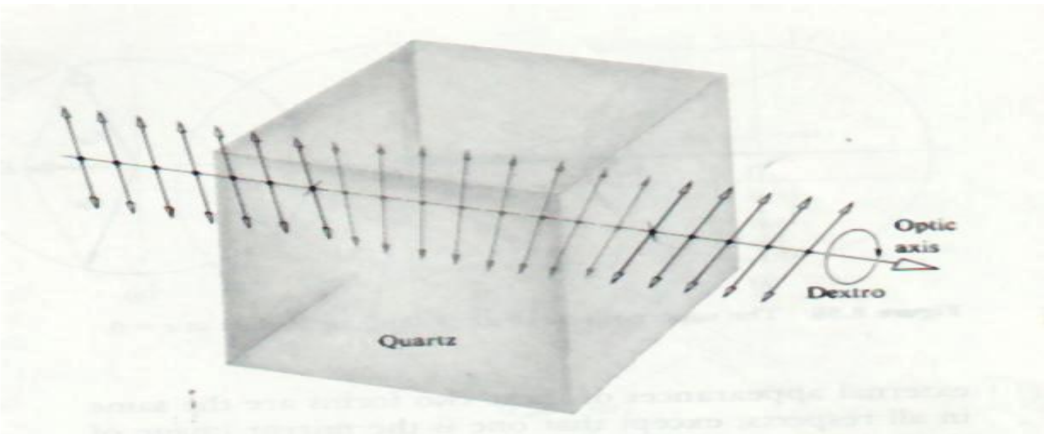


Fig. (2.11): optical activity of quartz.

The rotation depends on both the wavelength of light and the thickness of the active medium. The net angle of rotation β is

$$\beta = \rho L d, \qquad (2.3)$$

where β: angle of rotation.

ρ: specific rotation that produced by 1-mm plate of optically active solid (in degrees) (see table 2.1).

L: light path through the solution in decimeters.

d: the concentration of the solution in grams per cm^3.

Optical wavelength λ (nm)	Specific rotation (ρ) in degree.
226.503	201.9
404.656	48.945
435.834	41.548
546.072	25.535
589.29	21.724
670.786	16.535

Table (2.1): shows the specific rotation of quartz that produced by 1 mm plate of optically active solid. (Frank 1996).

If the sign of the rotation angle is positive, this means that, the material is dextrorotatory into the optical activity, for example the angle of rotation of quartz about 22° per mm of propagation. (Lipson et all 1995),while the sign of the rotation angle negative, then the material is levorotatory into optical activity, i.e. the angle of rotation of 1 dm of turpentine is -37°.(Frank 1996). Moreover, the rotating angle of sodium nitrite, which was a biaxial crystal, is 15.7° per mm for light at 632.8 nm. (Nussbaum and Phillips. 1976).

In 1825 Fresnel explain the logical description of the optical activity, so in the materials that possess optical activity, the velocity of propagation of polarized light (circularly) is different for different directions of rotation v_L and v_R, and shows circular birefringence, i.e. the crystal has refractive indices n_R and n_L for right and left circularly polarized light, see table (2.2). (Wilson and Hawkes 1983). This leads to the phase difference to be introduced between them for different distances through the crystals. See fig. (2.12).

Case I: If the phases of the L and R components are equal. (When v_L and v_R, equivalently, $n_L = n_R$, and $K_L = K_R$, where $K = \frac{w}{c}$ is the propagation vector).

When the incident light is linearly polarized along x-direction, then the vector sum of electric vectors oscillating along the x-axis as the E_R and E_L vectors rotate clockwise and counterclockwise. See fig. (2.12).

Case II: If the phase of the L and R components is not equal $n_R \neq n_L$, then the phases of the two components are:

$$\left.\begin{aligned}\Theta_L &= K_L L - wt\\ \Theta_R &= K_R L - wt\end{aligned}\right\} \text{..} (2.4\text{-a})$$

where $k_L = \frac{w}{c} n_L$, $k_R = \frac{w}{c} n_R$, then the angle of rotation, L: the thickness of active medium.

$$\beta = \frac{1}{2}(\Theta_L - \Theta_R) =$$

$$\beta = \frac{1}{2} L[K_L - K_R]$$

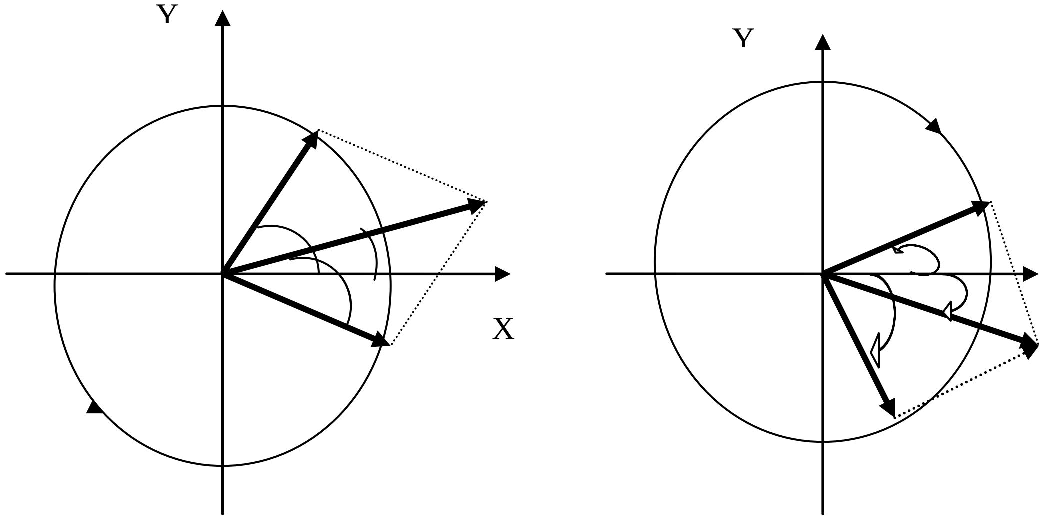
$$\beta = \frac{1}{2} L\left[\frac{w}{c} n_L - \frac{w}{c} n_R\right]$$

$$\beta = \frac{1}{2} L \frac{w}{c}[n_L - n_R]$$

$$\beta = \frac{1}{2} L \times \frac{2\pi f}{c}[n_L - n_R]$$

$$\beta = \frac{\pi L}{\lambda_o}[n_L - n_R] \text{..} (2.4-b)$$

If $n_L > n_R$ the medium is levorotatory, and if $n_R > n_L$, the medium is dextrorotatory. See fig. (2.12).



a- Levorotatory $n_L > n_R$ b- Dextrarotatory: $n_R > n_L$

Fig. (2.12): shows optical rotation produced by left and right circularly polarized light for different speeds through an active material.

The liquids, complex organic compounds, exhibit optical activity, so the rotation is due to helical structure of the molecule. (Nussbaum and Phillips 1976). The amount of rotation through liquids is less than the rotation through solids (Frank 1996). Sugar solutions are optical activity, so the rotation depends on the concentration. The angle of rotation of the linearly polarized light is proportional to the thickness of active medium as in equation (2.4-b) (Frank 1996).

Table (2.2) The R – L indices for different wavelengths.

material	wavelength (nm)	refractive index	
		n_R	n_L
$ADP(NH_4H_2PO_3)$	214	1.5974	1.626
	405	1.4916	1.5397
	633	1.4773	1.4773
Quartz	198	1.6639	1.6509
	394	1.5681	1.5585
	768	1.548	1.539
Calcite	242	1.5378	1.7811
	410	1.4964	1.5585
	643	1.4849	1.655
Rutile (TiO2)	436	3.216	2.836
	691	2.852	2.555

2.5.6- The magneto-optic effect (Faraday Effect):-

The Faraday or magneto-optic effect was one of the earliest indications of the interrelationship between electromagnetism and light. (Zajic 1987). Faraday after ten years search observed that magnetic field applied to glass caused plane of polarization of light wave to rotate as it propagates in the field direction. (Nussbaum and Phillips. 1976). Michael Faraday in 1845 found that when a beam of plane polarized light passes through a substance subjected to a magnetic field, so the emerging light is found to remain linearly polarized, but with a net rotation angle β of the plane of polarization that is proportional both to the thickness L of the sample or substance and the amount of magnetic field component parallel to the direction of propagation. (Wilson and Hawkes 1983), (Frank 1996). Maxwell in 1857 showed that experimental foundations of electricity and magnetism could be expressed by four equations, and predicted electromagnetic wave and explained Faraday's work. (Nussbaum and Phillips. 1976). Faraday Effect or rotation is similar to the optical activity effect, but there is an important difference in the two effects. In Faraday effect the sense of relation of the plane of polarization is independent of the direction of propagation, and the sign of magneto-optic effect, because after the reflection, the propagation of polarized light is reversed as B (magnetic flux density), so the net result is twice the effect, while in optical activity the sense of relation is related to the direction of propagation of light (Wilson and Hawikes 1983). The Faraday rotation of polarizated light can be understood as circular birefringence that existence of different indices of refraction for left and right circularly polarized components, so each component is affected differently by the applied magnetic field and traverses the sample with different speed, since the refractive index is different for the two components. (Frank 1996). The theory of Faraday effect involves the quantum mechanical theory of dispersion including the effects of magnetic field (B) on the atomic, or molecular energy levels, so there will be two possible valves of the electric dipole moment, the polarization, and permittivity, so that two refractive indices for left and right –handed polarization n_R, and n_L , then the difference of refractive indices:

$$\Delta n = n_L - n_R = n_o^3 \times r_B \times B \qquad (2.5)$$

The relation in Faraday effect can be doubled by reflecting the light because after reflection, the propagation of polarized light is reversed as magnetic field (B_o), so the net result is twice or double the effect and the angle of the plane of polarization per unit of propagation distance is :-

$$\beta = \frac{e\lambda}{2mc} \times \frac{dn}{d\lambda} \times BL \ldots\ldots (2.6-a)$$

$$\beta = VBL \ldots\ldots (2.6-b)$$

$$V = \frac{e\lambda}{2mc} \times \frac{dn}{d\lambda} = 1.0083\lambda \times \frac{dn}{d\lambda}$$

where V: (Verdant constant) $=1.0083\lambda \times \frac{dn}{d\lambda}$, that measured in (minute per Gauss cm). See table (2. 3)

B: magnetic flux density.

L: path length in the substance in cm.

Table (2.3), Verdant constant for some substances, for wavelength λ = 589 nm. (Zajic 1987).

Material	**Temperature (C°)**	**V (minute of arc gauss $^{-1}$ cm $^{-1}$)**
Light flint glass	18	0.0317
Water (H_2O)	20	0.0131
NaCl	16	0.0359
Quartz	20	0.0166
$NH_4Fe(SO_4)_2$. 12 H_2O	26	- 0.00058
Air (λ = 578 nm and 760 mm Hg.	0	6.27×10^{-6}
CS_2		0.0423
CCl_4		0.0160
KCl		0.02858
ZnS		0.225

The angle of rotation in terms of n_R, n_L is:

$$\beta = \frac{2\pi L}{\lambda_o}(n_L - n_R) \qquad \textbf{(2.7)}$$

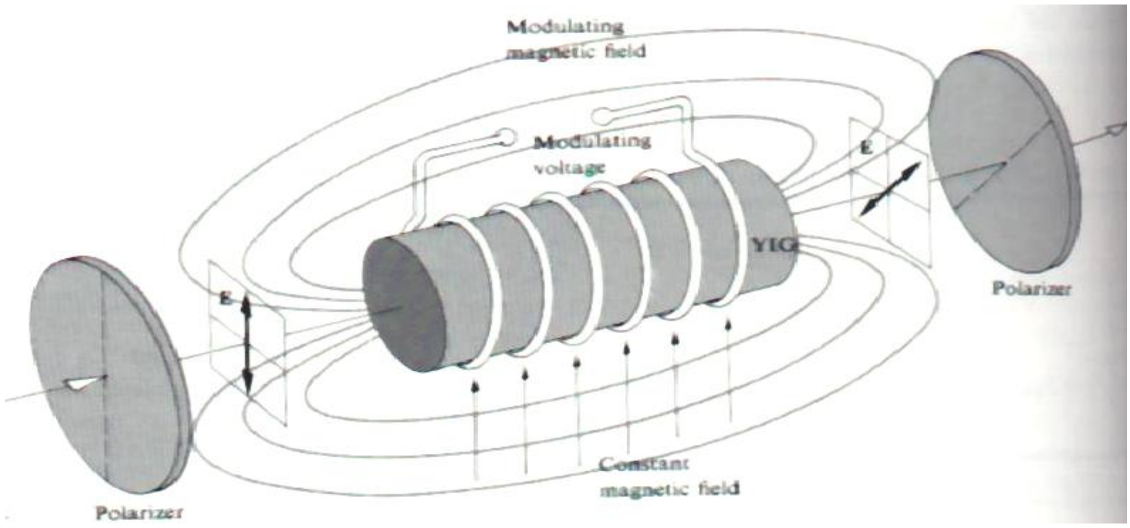


Fig.(2.13) Faraday modulator. (Zajic 1987).

2.5.7- Kerr effect:

Kerr effect was the first electro-optic effect discovered in glass by the Scottish physicist Kerr in 1875 (Zagic 1987 and Frank, 1996). In 1893 Pockels found the general theory of this effect that involved crystal symmetry (Nussbaum and Phillips, 1976). When an isotropic material is placed in an electric field, it becomes birefringent with optic axis parallel to the induced electric field (Frank, 1996). The materials can be divided into two types:-

i. Isotropic materials or (medium), in which the propagation of light waves is independent of the refractive index.

ii. Anisotropic material (crystal or liquid), in which the propagation of light waves depends on the refractive index. This type is suitable for fabricating polarizer's and optical modulators. If an electric field is applied a cross an optical medium, then the polarization and the refractive index of the medium will change (Wilson and Hawkes, 1986). The difference in the refractive indices is proportional to the square (or a polynomial) of the applied electric field E (Frank, 1996):

$$\Delta n \propto E^2 \qquad (2.8)$$

$$\frac{1}{n^2} = \frac{1}{n_o^2} + rE + RE^2 \qquad (2.\ 9)$$

Where r is the linear electro-optic coefficient and R is the quadratic electro-optic coefficient (Wilson and Hawakes, 1983), (see table 2.6).

Kerr effect is proportional to the square of the electric field and is often referred to as the quadratic electro-optic effect (Zagic 1987). Kerr effect occurs whether or not a material possesses inversion symmetry (Frank, 1996). The idea of Kerr effect was employed in the construction of the Kerr shutter, or optical modulator (see Fig. 2.14). The shutter consists of:-

1. Glass cell containing two electrodes filled with a polar liquid.
2. Plate electrodes lying in the glass box parallel to each other.
3. Two linear polarizer's whose transmission axis is at $\pm 45^{o}$ to the applied electric field, as shown in Fig. (2.14-a)

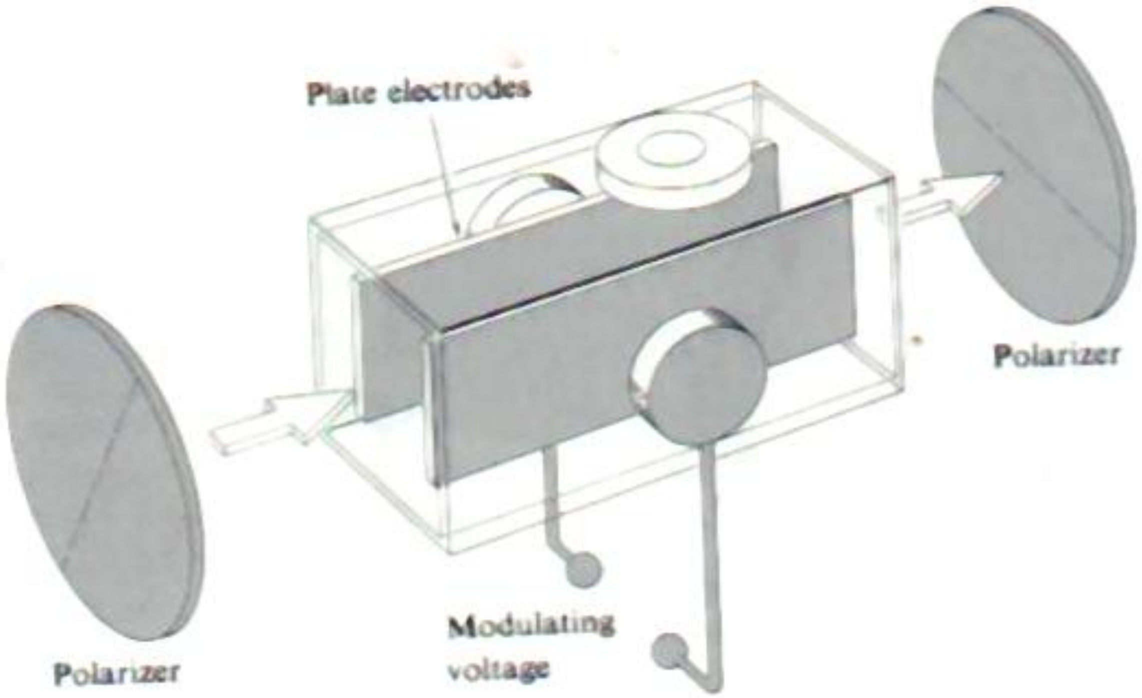


Fig. (2.14): A photo of Kerr optical Modulator (After Zajic, 1987).

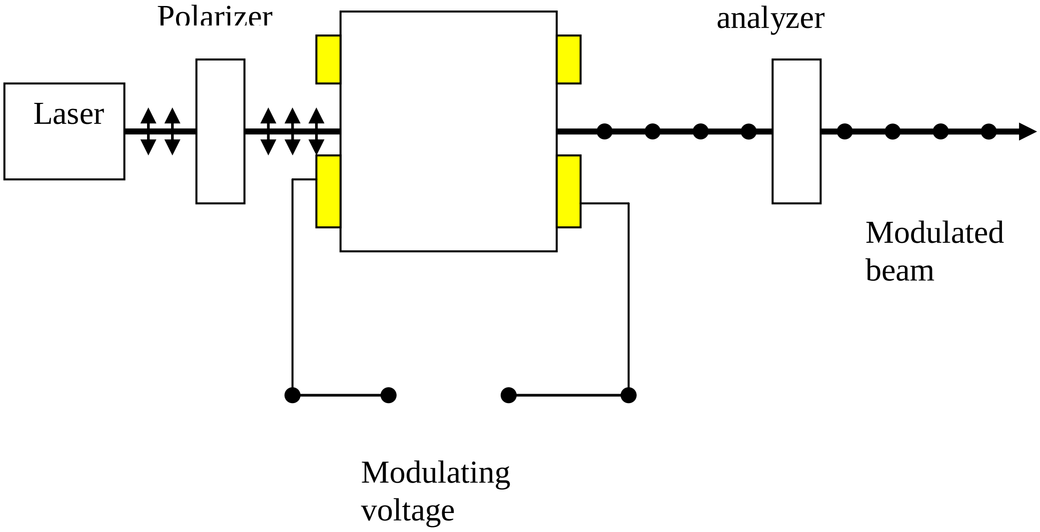


Fig.(2.14-b):- Block diagram of an electro-optic crystal used to modulate a light beam (redrawn from Nussbaum and Phillips).

When Kerr cell is filled with one of isotropic liquids (i.e. nitrobenzene) and is placed between two electrodes connected to a voltage source. The cell is then fixed between Polaroid's. The whole arrangement is used as an optical switch or modulating cell. This allows modulation frequency up to 10^{10} Hz. The applied electric field induced birefringence with an optic axis parallel to the applied electric field. The light beam is found to divided into two components, one called ordinary (o-ray) that passes straight through the material, the other called extraordinary (e-ray) diverges as it passes through the material and the emerges parallel to its original direction, so the field of o-ray normal where the field of e-ray parallel to principle field (see Fig. 2.15).

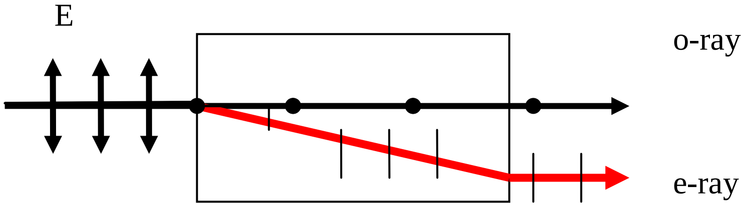


Fig.(2.15): A light of two orthogonal field components traversing the martial (redrawn Zajic, 1987).

There are two refractive indices for polarizations parallel to and perpendicular to the optic axis when that light traversing the cell, then the phase shift between the two refractive indices is (Frank, 1996) as in equation (2.9) is

$$|\Delta n| = \frac{R}{2} n_o^3 E^2 \qquad (2.\ 10)$$
$$\Delta n = K E^2 \lambda$$

Where K = $\frac{R}{2\lambda} \times n_o^3$ is Kerr constant.

The phase shift introduced by the field for the ordinary and extraordinary wave components is:

$$\varphi = \frac{2\pi\Delta n}{\lambda} = \frac{2\pi K V^2 L}{d^2} \qquad (2.11)$$

Where V= E $\times$ d, applied voltage measured in volts

d: plate separation measured in cm.

K: Kerr Coefficient.

L: electrode effective length.

From the equation 2.11 it is seen that the phase shift produced depends only on the total applied voltage and independent of the material length. The Kerr cell behaves as a half wave plate with phase shift equal (π) at the voltage applied on the Kerr cell equal V_{HW} = d / $\sqrt{2KL}$.

The half and quarter wave voltages for a Kerr cell, with length = 2.54 cm and electrode space d at 2.54 cm for nitrobenzene for different wavelengths as shown in Table (2.4).

Table (2.4):-

Wavelength (μm)	Quarter-wave voltage (kV)	Half-wave voltage (kV)
0.5	26.2	37
0.7	32	45.2
1.06	39.4	55.6

Table (2.5) Kerr constant for some materials at light wavelength (λ = 589 nm) (After Frank, 1987, Zajic, 1987 and Wilson and Hawkes, 1983)

Material (λ = 589 nm)	**Chemical formula**	**K (in units of 10^{-12} m $\times$volt^{-2}) (Pm/V^2)**
Nitrogen(STP)	N_2	4×10^{-6}
Benzene	C_6H_6	0.6
Glass (typical)		0.001
Carbon disulfide	CS_2	0.036
Water	H_2O	0.052
Nitrotoluene	$C_5H_7NO_2$	1.4
Nitrobenzene	$C_6H_5NO_2$	2.4
Chloroform	$CHCl_2$	- 0.0035

The emerging intensities of light with polarized directions along orthogonal directions are dependent on the size of Δn. For linearly polarized light that is incident at 45^o to axes of the Kerr cell, the transmitted intensity with the same polarization direction as the incoming light, which is the intensity that would be transmitted through a parallel polarizer, is given by the $T_{||}$; the intensity that would be transmitted through a crossed polarizer is given by the $T_{\perp}$ (see Fig. 2.18):

$$\left.\begin{aligned} T_{||} &= \cos^2(\varphi) = \cos^2\left(\frac{2\pi K V^2 L}{d^2}\right) \\ T_{\perp} &= \mathrm{Sin}^2(\varphi) = \sin^2\left(\frac{2\pi K V^2 L}{d^2}\right) \end{aligned}\right\} \qquad (2.12)$$

The Kerr cell that filled with nitrobenzene can be used as an electro–optic shutter for measuring the speed of light (Wilson and Hawkes, 1986), and used extensively as Q-switches in pulsed laser system (Zajic, 1987), and as mechanical light choppers that response in frequencies in the range 10^{10} Hz (Frank, 1996).

2.5.8 - Pockels effect:-

This effect was discovered in 1893 (Frank, 1996) and named after the German physicist Friedrich Carl Alwin Pockels (1865-1913) (Zajic, 1987). Pockels effect was a special case of two waves mixing, where one of the waves is incident optical wave and the other a field of zero frequency, DC field (Frank, 1996). The first cell used for Pockels effect the change of the refractive index of a material depends on electric field, hence according to equation (2.9). Pockels effect is a second order effect relative to the polarization and it is a linear electro-optic effect (Frank, 1996). The difference between the Pockels cell and the photoelastic modulator (see section 2.5.9) is that pockels cell need high voltage relative to photoelastic modulators. In Pockels cell a solid martial is used while in Kerr cell samples are usually liquids. Note that, there are 32 crystal symmetry classes, 20 of which may show Pockels cell effect (Zajic, 1987). All crystalline materials exhibiting a Pockels effect are also piezoelectric, that they induce birefringence due to mechanical strain (Frank, 1996). There are two common cell configurations, i.e. transverse and longitudinal depending on the applied electric field direction. In a transverse Pockels cell, the applied electric field should be in the direction of the propagation of the light beam, then the net phase shift or total retardation between two waves is:-

$$\Delta\Phi = \Phi_{ne} - \Phi_{no} = \frac{2\pi}{\lambda} \times r \times n_o^3 \times V \qquad (2.13)$$

where λ :is the wavelength measured in nm.

n_o : the ordinary index of refraction .

V: applied voltage in volts.

The amount of phase shift is proportional to the applied voltage. The pockels cell behaves as a half wave plate with phase shift equal (π) at an applied voltage equal to

$V_{HW} = \dfrac{\lambda_o}{2 \times r \times n_o^3}$. For example: suppose that cell is made from a KDP (potassium dideuterium phosphate- KD_2PO_4) crystal of 1 cm thickness and the optical wave has a wave length of 549.1 nm and r =10.6 x 10^{-12} m/V, n_0 = 1.51. The half wave-voltage is ≈ 7.6 x 10^3 Volts. See table (2.6).

Material	Wavelength (nm)	Linear electro-optic coefficient r Pm/V)	Refractive index n_0	Half wave voltage (kV)
Potassium dihydrogen phosphate (KH_2PO_4) KDP	633	11	1.51	8.36
Potassium dideuterium phosphate (KD_2PO_4) KD*P	633	24.1	1.51	3.81
Ammonium dihydrogen phosphate ($NH_4H_2PO_4$) ADP	546	8.56	1.48	9.84
Lithium niobate ($LiNbO_3$	633	30.9	2.29	0.85
Lithium tantalite($LiTaO_3$)	633	30.5	2.18	1
Gallium arsenide (GaAs)	10600	1.51	3.3	98
Zinc Sulfide (ZnS)	600	2.1	2.36	10.9
Quartz	633	1.4	1.54	61.9

Table (2.6) list of some pockels materials with its half wave voltage (After Frank, 1996).

Most KD*P (see table 2.6) Pockels cells are longitudinal-field devices, while $LiNbO_3$ (see table 2.6) and BBO Pockels cells are transverse-field devices.

In a longitudinal Pockels cell, the applied electric field is parallel to direction of propagation of light beam such that fast and slow axes are induced in a plane normal to the applied field, as shown in Fig. (2.17). If the pockels cell crystal is rotated until the FA (fast axis -see Fig. 2.17) and SA (slow axis- see Fig. 2.17) are 45° to the x and y axis, a vertically polarized light wave E_o incident on the crystal along the field direction has equal amplitude component on FA and SA. These components have different refractive indices and different speeds through the crystal, and then the crystal behaves as a phase retarded. The emerging wave components with phase difference:

$\Phi = 2\ \Delta\Phi$, where $\Delta\Phi = \frac{2\pi}{\lambda_o} \times L \times \Delta n$, where

L Δ n : is the optical path difference.

$$\Delta n \approx \quad d\left(\frac{1}{n^2}\right) = r \times E$$

$$= -2\frac{dn}{n^3} = r \times E \text{ r E, then}$$

$$|\Delta n| = \frac{n_o^3 \times r_o \times E}{2} \qquad (2.14)$$

$$\Phi = \frac{2\pi}{\lambda} \times r \times n_o^3 \times E \times L = \frac{2\pi}{\lambda} \times r \times n_o^3 \times (\frac{V \times L}{d}) \qquad (2.15)$$

where L: length of crystal. d: electrode spacing.

V: applied voltage.

From equation 2.11 Δn induced birefringence due to the increase in the refractive index for light polarized along the slow axis (SA) by $\frac{\Delta n}{2}$, and the decrease in refractive index for light polarized along the fast axis by $\frac{\Delta n}{2}$.

The half wave voltage for transverse field Pockels cell is proportional to $(\frac{d}{L})$, i.e. to the electrode spacing divided by crystal length, while for longitudinal Pockels cell, the half wave voltage is independent of crystal length. The emerging intensities of light with polarized directions along orthogonal directions are dependent on the value of Δn. For linearly polarized light that is incident at 45° to the fast and slow axes of the pockels cell, the transmitted intensity with the same polarization direction as the incoming light, which is the intensity that would be transmitted through a parallel polarizer, is given by the $T_{||}$; the intensity that would be transmitted through a crossed polarizer is given by the $T_{\perp}$ (see Fig. 2.18):

$$\left.\begin{aligned} T_{||} &= \cos^2\left(\frac{\phi}{2}\right) = \cos^2\left(\frac{\pi \times \Delta n \times L}{\lambda}\right) \\ T_{\perp} &= \sin^2\left(\frac{\phi}{2}\right) = \sin^2\left(\frac{\pi \times \Delta n \times L}{\lambda}\right) \end{aligned}\right\} \qquad (2.17)$$

***For example*:-** for GaAs (see table 2.6), if r = 24.1 x 10^{-12} m/V, and refractive index is 1.51 and λ_o = 1060 nm then V_{HW} = 6390 Volts, this means that the crystal needs 6.4 kV to transform into a half wave plate. The (r) coefficient of KD*P (see table 2.6) is largely independent of wavelength although it is sensitive to temperature changes. For Q-switching applications, the quarter-wave voltage at 1064 nm is about 3200 volts. The (r) coefficient of $LiNbO_3$ (see table 2.6) varies with wavelength and with modulation frequency. For Q-switching applications, the quarter-wave voltage at 1064 nm with d = 9 mm and L= 25 mm is about 1650 volts. The (r) coefficient of BBO is quite a bit smaller than either (r) of KD*P or r_{22} of $LiNbO_3$. BBO is useful when operation requires extremely high peak power or average power light flounces. For Q-switching applications, the quarter-wave voltage at 1064 nm with d = 4 mm and L= 20 mm is about 4350 volts.

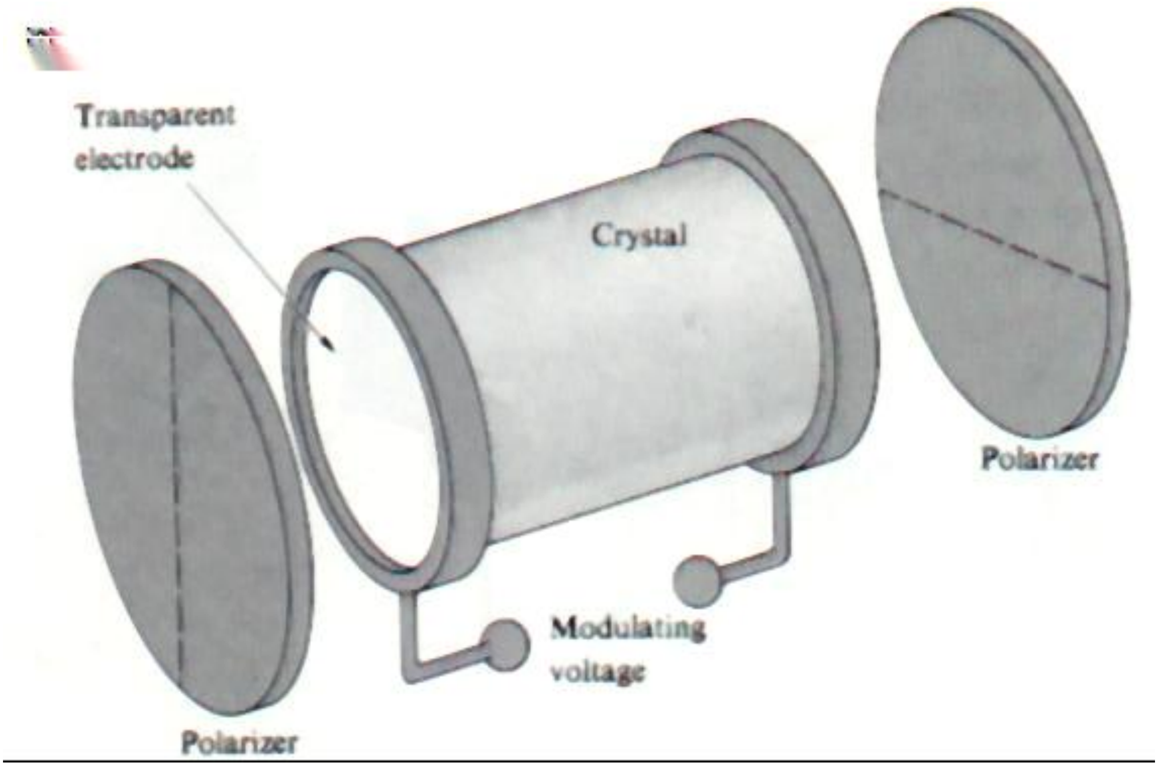


Fig. (2.16): The photo of Pockels cell (After Zajic, 1987).

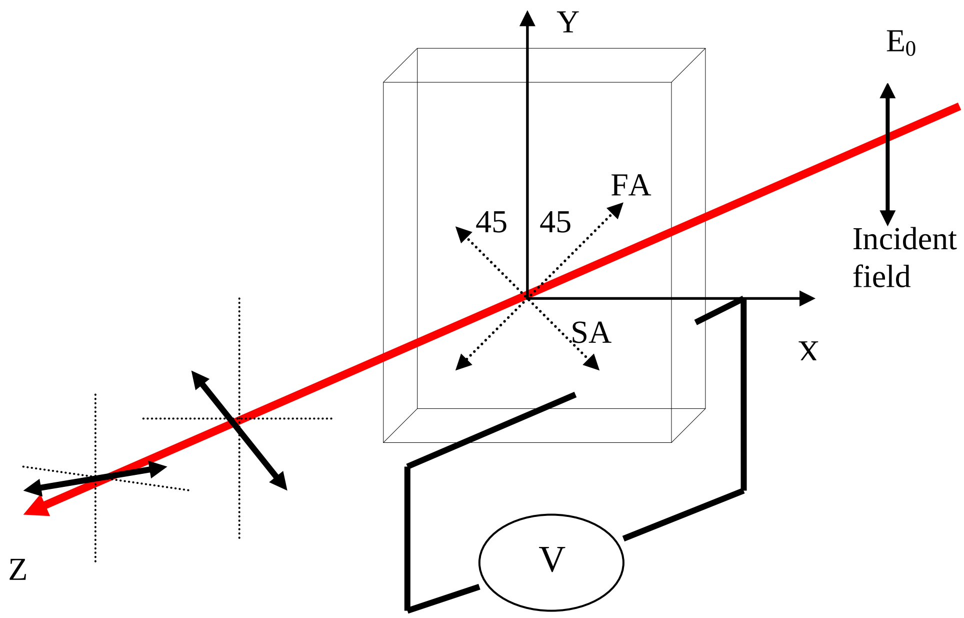


Fig. (2.17): Schematic showing the phase shifts due to voltage V application to Pockels cell (redrawn from Frank).

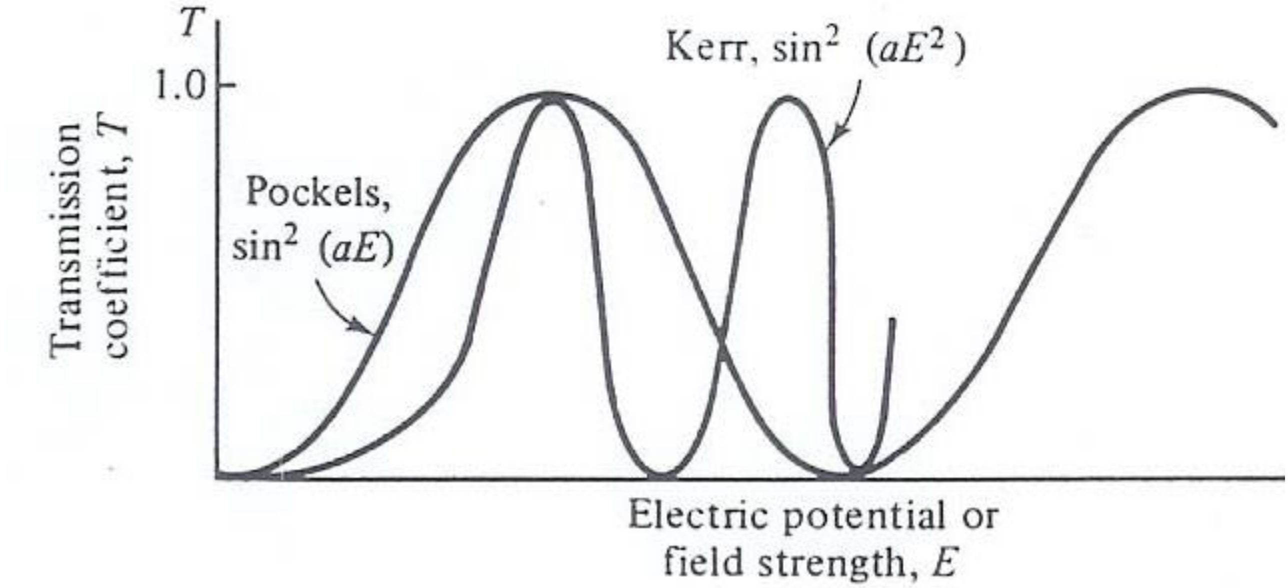


Fig. (2.18) shows the transmission for Kerr and Pockels cell that placed between crossed polarizer's (After Nussbaum and Phillips, 1976).

Pockels cells can be configured to appear either as a capacitive load or as a portion of a coaxial transmission cable. Most INRAD Pockels cells are configured as capacitive loads with a typical capacitance of about 10 pF.

2.5.9 -Photo elastic effect:-

In 1816, Brewster discovered that normal isotropic substances could be converted to anisotropic substances by mechanical stress (Zagic 1986). The basic of this effect is the indicatory of an isotropic medium such as glass, Perspex, or various epoxy resins that can be effected by a strain field, the material becomes uniaxial with its axis a long that of the strain (Lipson 1995). The photo elasticity is the change in refractive index of a crystal due to mechanical stress (Frank 1996). The retardance at any point on the sample is proportional to the principle stress difference ($\sigma 1$ – σ_2) (Zajic, 1987), where σ's are orthogonal principle stresses. The photo elastic modulator (Fig.2.19) contains an optical part (block), that typically an isotropic block of fused silica. Many ordinary materials such as plastic or glass can also show a birefringence and colors under normal condition or under stress, when material inserted between two polarizer's as in Fig. 2.19, so light must pass through two or more thickness at certain point, with phase shift $\Delta\varphi$ from point to point due to the change in refractive indices changes (Frank, 1996), see Fig. 2.19. When an electric field of the incident linear light is parallel to either stress axis, the wave pass through the sample un effected, while crossed the polarizer light will be absorbed. The phase difference $\Delta\varphi$ introduced by a retardation plate is dependant on the wavelength (Frank, 1996)

$$\Delta\varphi = \frac{2 \times \pi \times d}{\lambda_o}(n_{\perp} - n_{||}) \qquad (2.18)$$

Where d is the thickness of the plate, λ_o: vacuum wavelength, n: material refractive index for parallel, and perpendicular incident light components.

If $\Delta\varphi = \pi$, the retarded materials plates which are thin called zero order i.e. Mica and Quartz, and for thick plates the $\Delta\varphi = 2\ m\ \pi + \pi/2$, where m = 1, 2, 3, 4. Are called higher order (Frank, 1996), these plates known as compensators, see Fig. 2.20.

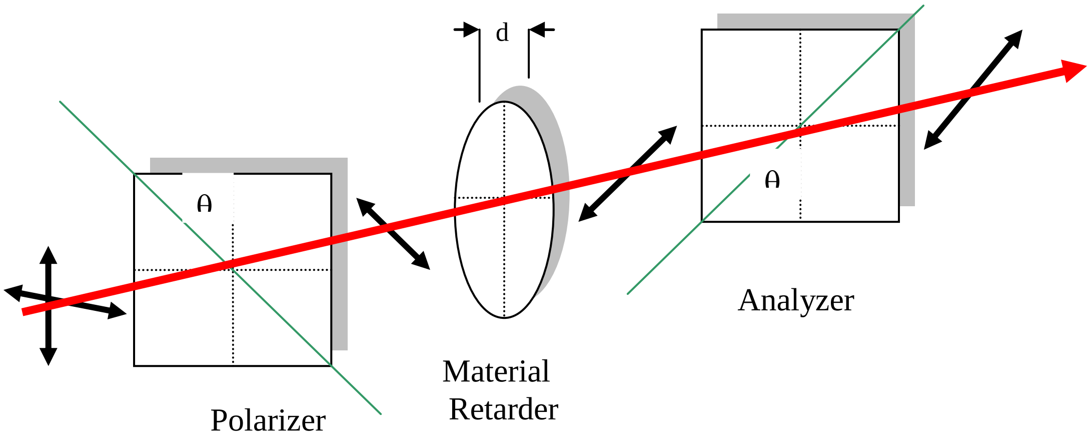


Fig. (2.19): Two polarizing sheet whose transmission axis with an angle θ to each other.

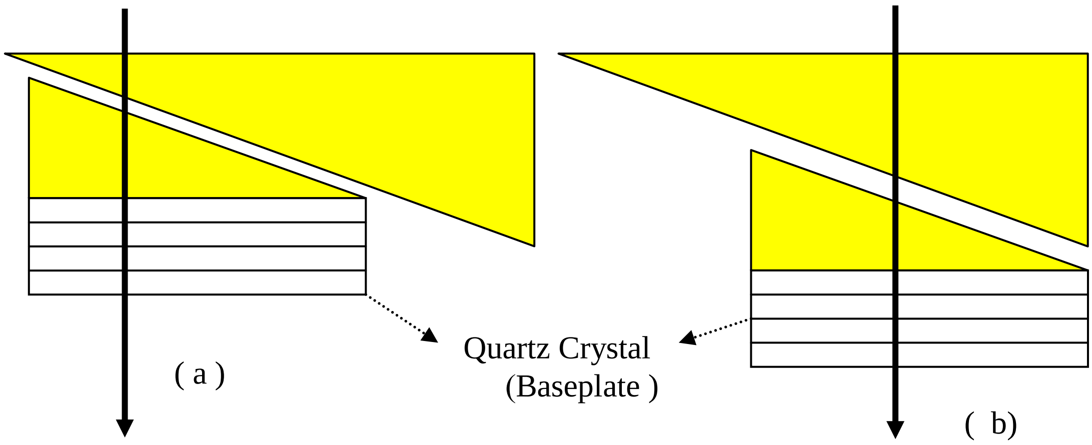
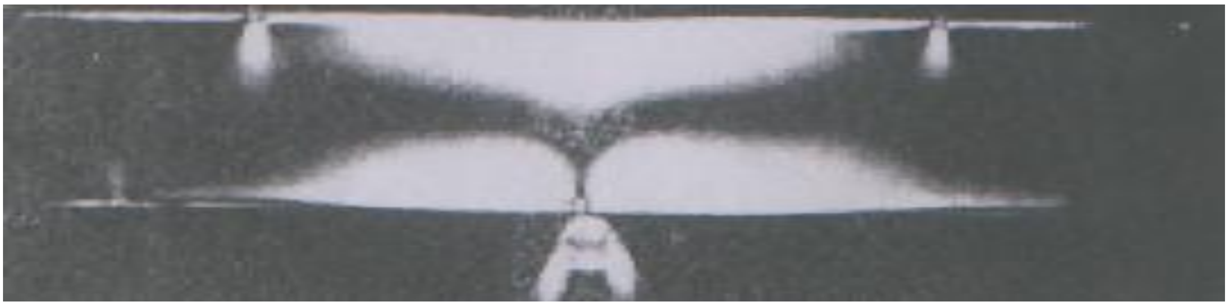


Fig. (2.20): Soleil-Babinet compensator. (a)- Zero order retardation (b) - Maximum retardation.

Table (2.7): The refractive indices for several materials measured at sodium wavelength of 589.3 nm (Frank, 1996).

Material	Samples	$n_{\|\|}$	$n_{\perp}$
Isotropic (Cubic)	Sodium chloride	1.544	
	Diamond	2.417	
	Fluorite	1.392	
Uniaxial- trigonal, tetragonal, hexagonal	Ice	1.313	1.309
	Quartz (SiO_2)	1.5534	1.5443
	Zircon ($ZrSiO_4$)	1.968	1.923
Uniaxial- (trigonal, tetragonal, hexagonal)	Rutile (TiO_2)	2.903	2.616
	Calcite ($CaCO_3$)	- 1.4864	- 1.6584
	Tourmaline	- 1.638	- 1.669
	Sodium Nitrate	- 1.3369	1.5854
	Beryl ($Be_2Al_2(SiO_3)_6$	- 1.590	- 1.598
Biaxial (Triclinic, monoclinic, orthorhombic)	Gypsum ($CaSO_4(2H_2O)$	1.520	1.530
	Feldspar	1.522	1.530
	Mica	1.552	1.588
	Topaz	1.619	1.627

To produce retardation, a standing compression wave, is set up in the optical block by driving it at its resonant frequency, with an electrical transducer that cemented to its side. An important use of photo elastic modulators is as polarization modulators in modern circular diachronic instruments (Kligers *et. Al. 1990*).



(a)

(b)

Fig. **(**2. 2**1)** Photo elastic stress patterns for a beam resting on two supports (a) lightly loaded at the center. (b) Heavily loaded at the center (After Frak, 1996).

2.5.10 - Acousto-optic modulators:

The acousto-optic effect is the change in the refractive index of the medium that caused by the photo elastic effect occurred in all optical materials on the application of a mechanical stress (Wilson and Hawakes 1989).

Acousto-optic devices are used in laser equipment for electronic control of the intensity and position of the laser beam. Acousto-optic interaction occurs in all optical mediums when an acoustic wave and a laser beam are present in the medium. In this technique the angular deflection is proportional to the acoustic frequency. Acousto-optic effect is three dimensional diffraction effect (Lipson *et. al*. 1995). When an acoustic wave is launched into the optical medium, it generates and change a refractive index wave that behaves like a sinusoidal grating of wavelength λ which caused by photo elastic effect (see Fig 2.22). The acoustic wave velocity is very much less than the light wave velocity, so it is assumed to consider the variation in refractive index to be stationary in the medium, (Wilson and Hawkes 1983).

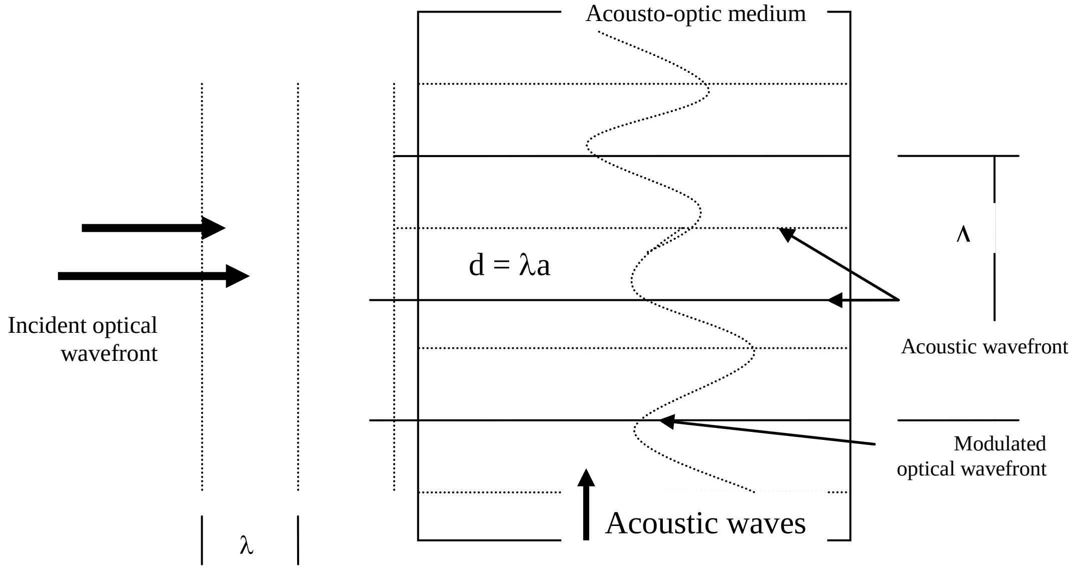


Fig.(2.22): Schematic illustration of acousto-optic modulation. The acoustic waves change the refractive index of the medium.

An incident laser beam passing through this grating will diffract into several orders according to diffraction equation (Frank, 1996):

$$m\lambda = d \sin \theta_m \qquad (2.19)$$

where λ is the incident laser wavelength, d: grating constant equal to the acoustic wavelength λ_a, and θ_m is the diffraction angle in m^{th} order, m = 0, ±1, ±2, ±3,

Here are two main cases:-

a- The Raman–Nath regime (transmission-type) as in Fig. 2. 23 : In this regime the acoustic diffraction grating is thin (the crystal is thin), so the light is not redistributed before leaving the modulator (Wilson and Hawkes 1983), this means that variation in refractive index is corresponding to variation in light speed, so the crystal behaves as a transmission phase grating (Frank, 1996). The intensity of the light depends on the acoustic grating, which is related to the amplitude of acoustic modulating wave (Wilson and Hawkes 1989).

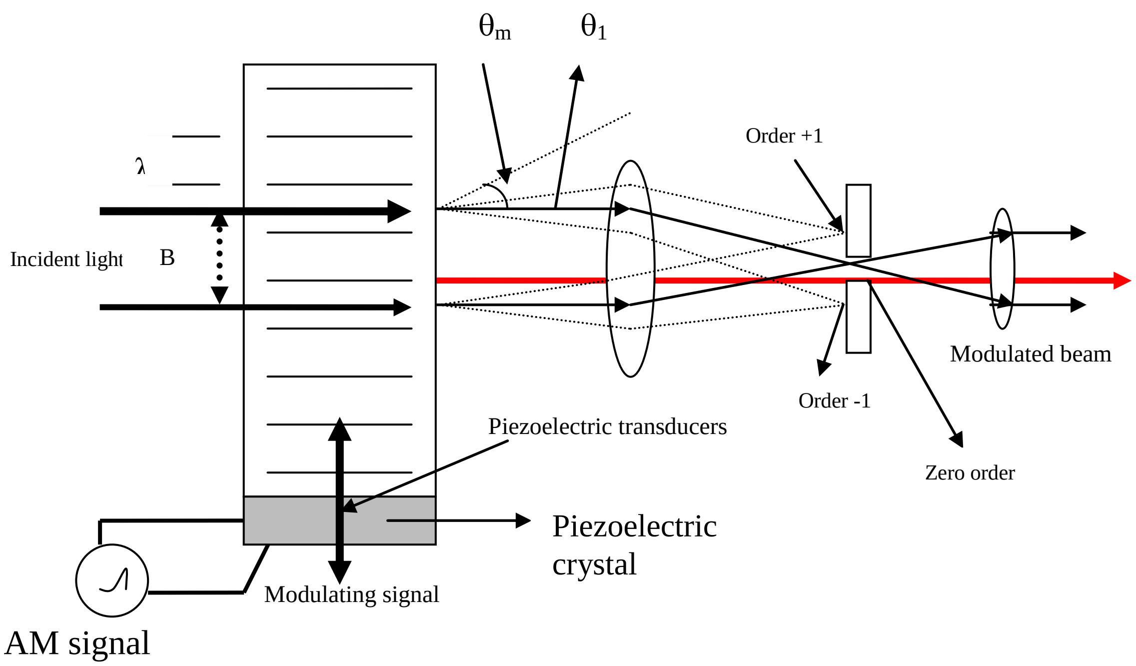


Fig.(2.23): Raman–Nath (transmission-type) acousto-optic diffraction grating modulation (redrawn from Frank).

b- The Bragg regime (reflection -type) as in Fig. 2.24: In this regime the acoustic diffracting grating (Crystal) is thicker, so the light is re-diffracted before leaving the acoustic field (Frank, 1996), similar to X-ray diffraction (Wilson and Hawkes 1983). Note that the acousto-optic device is called Bragg cell. The acousto-optic Brag cell is widely used as active element for spatial or temporal modulation of light intensity and its distribution (Jakab and Peter 1989).

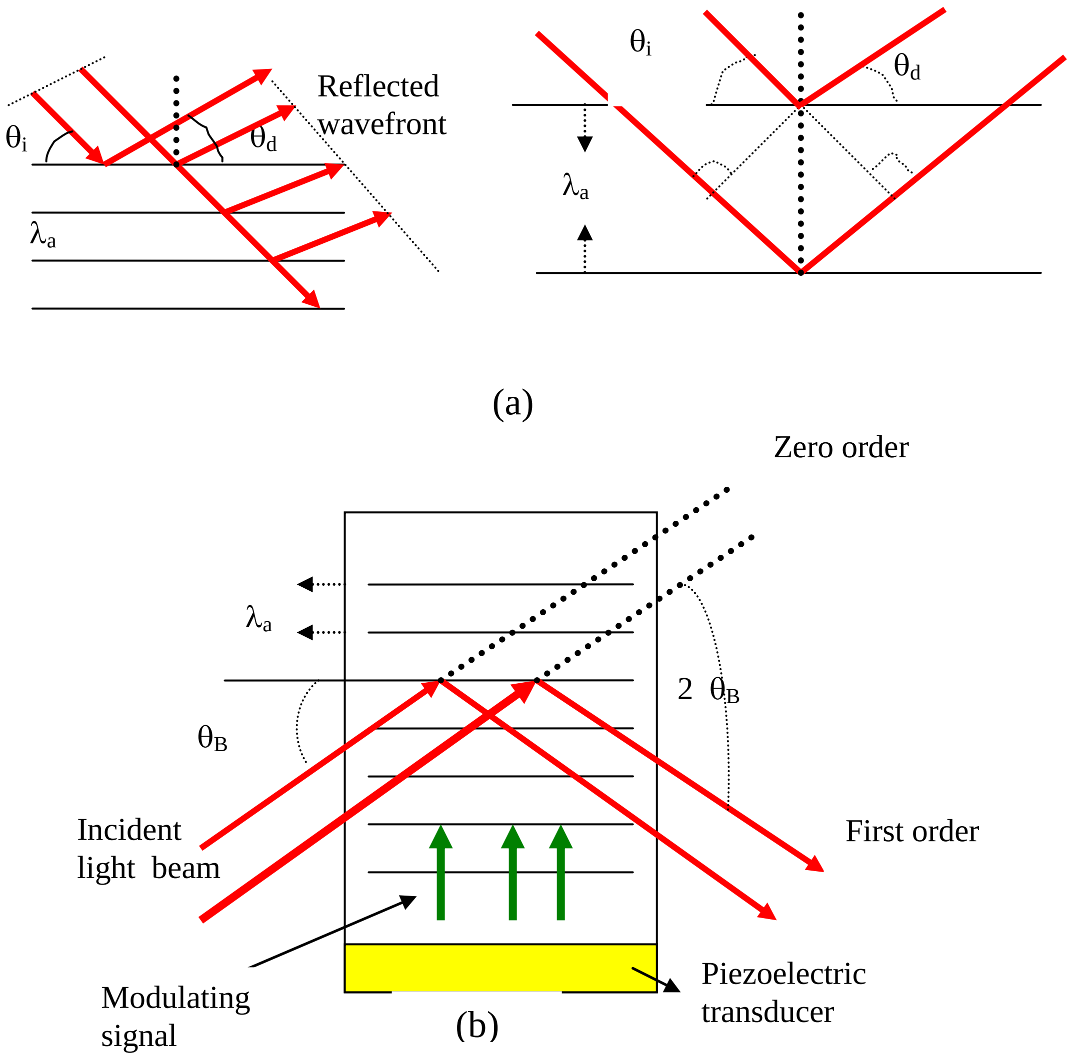


Fig. (2.24): The Bragg (or reflection –type) acousto-optic diffraction grating modulation, (a)- the scattered of incident light (b)- The amount of reflected light (redrawn from Wilson and Hawkes 1983).

From the diffraction conditions $\theta_d = \theta_i$, where θ_d diffraction angle and θ_i incident angle.

$$\sin\theta_i + \sin\theta_d = \frac{m \times \lambda}{\lambda_a},\ m = 0,1,2,3,\ldots,\ \text{then}$$

$\sin \theta_i = \sin \theta_d = \frac{m \times \lambda}{2\lambda_a}$. In acousto–optic application used first order was in Fig.2.23-b, so

$\theta_d = \theta_B$ (Bragg angle).

$$\sin \theta_B = \frac{m \times \lambda}{2\lambda_a} \qquad (2.20)$$

At the Bragg angle the modulation depth (diffraction efficiency) is $\eta = \sin^2 (\frac{\phi}{2})$(Wilson and Hawkes 1989).

$$\phi = \frac{2\pi \times \Delta n \times L}{\lambda \times \cos \theta_B} \qquad (2.21)$$

Δn the amplitude of the refractive index and L the modulator length. The first order beam has the highest efficiency (η). Its angular position is linearly proportional to the acoustic frequency, so that the higher the frequency, the larger the diffracted angle:-

$$\theta = \frac{\lambda \times f_a}{v_a} \qquad (2.22)$$

where λ is the optical wavelength, f_a is the acoustic frequency, v_a is the acoustic velocity, and, θ, is the angle between the incident and the diffracted laser beam with the acoustic wave direction propagation at the base of the triangle formed by three vectors(See Fig. 2.25).

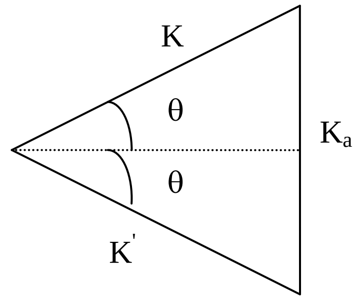


Fig. (2.25): The wave vector triangle (K incident wave, K': diffracted wave and K_a: acoustic wave) (redrawn from Frank).

The efficiency (η) or the fraction of light removed from the zero order beam is $\eta = \frac{I - I_o}{I_o}$, where I_o is the transmitted irradiance in the absence of the acoustic wave (Wilson and Hawkes 1983). The transmitted beam intensity or irradiance I_o depends on the acoustic power (P_a), because I_o is equal to the difference between incident light intensity (I_i) and the diffracted light intensity (I_d) (Voloshinov and Molchanov 1995). With acousto-optic, both deflection as well as modulation of the amplitude of the beam is possible. The acoustic waves which create diffraction grating are moving through the medium as reflected from the mirror, the reflected beam frequency changed as Doppler effect (Wilson and Hawkes 1983). The frequency shift is (Wilson and Hawkes 1983)

$$\Delta f = f^{`} - f_o = \pm 2 f_o \times v_a \times n \times \sin(\frac{\theta_d}{c}) \qquad (2.23)$$

where f_o: acoustic wave frequency, v_a: acoustic wave velocity, c: speed of light, n medium refractive index.

In the acousto-optic interaction, the laser beam frequency is shifted by an amount equal to the acoustic frequency. This frequency shift can be used for heterodyne deflection applications, where precise phase information is measured. A variety of different acousto-optic materials are used depending on the laser parameters such as laser wavelength (optical transmission range), polarization, and power density. For the visible region and near infrared region the modulators are commonly made from gallium phosphate, tellurium dioxide, indium phosphate, chalcogenide glass, single crystal quartz, or fused quartz. The tellurium dioxide shows optical activity, especially for waves propagating close to the optical axis direction (Gazalet, Ravez, Haine and Bridoux 1994). At the infrared region, germanium is the only commercially available modulator material with a relatively high figure of merit. Lithium niobate, indium phosphate, and gallium phosphate are used for high frequency (GHz) signal processing devices. The minimum time (transient time) of the acoustic wave across the optical beam is dependent on optical beam width (B) and the acoustic wave velocity (v_a), (see Fig. 2.23) (Frank, 1989).

$$t_{min} = \frac{B}{v_a} \tag{2.24}$$

So, the modulator bandwidth limit is ($\frac{B}{v_a}$). The acousto-optic modulators have some disadvantages; such as narrow frequency bandwidths of modulation and relatively low quick action, which is limited by the transient time of the ultrasound across an optical beam. Nevertheless in opto-electronic and laser technology there exists a wide range of technical problems that may be solved better by acousto-optic than by other types of modulators, i.e. opto-mechanical or electro optical and magneto optical devices (Voloshinov and Molchanov 1995).

2.6- Some applications of beam modulation:

The modulation of light beam can be used in many useful techniques as seen in previous sections, among these applications are:

1- Faraday rotator used as an optical isolator, this isolator consists of a Faraday rotator situated or placed between polarizer and analyzer pair, as in Fig. (2.26).The incident vertically polarized light is rotated 45^o counter (clock wise) by the Faraday rotator and this orientation is fully transmitted by the analyzer. The optical elements are responsible, back reflections (retro pulses) of this radiation a long the optical axis. In traversing the Faraday rotator a second time, the polarization vector of the reflected light is rotated an additional 45^o in the same rotation, so it emerges horizontally polarized and encounter the polarizer at an angle 90^o with the polarization direction of the original beam, so by this technique, it is rejected by polarizer, preventing it from continuing back into the optical system, where more is a high power laser system, so it will not damage the optical components (Frank 1996).

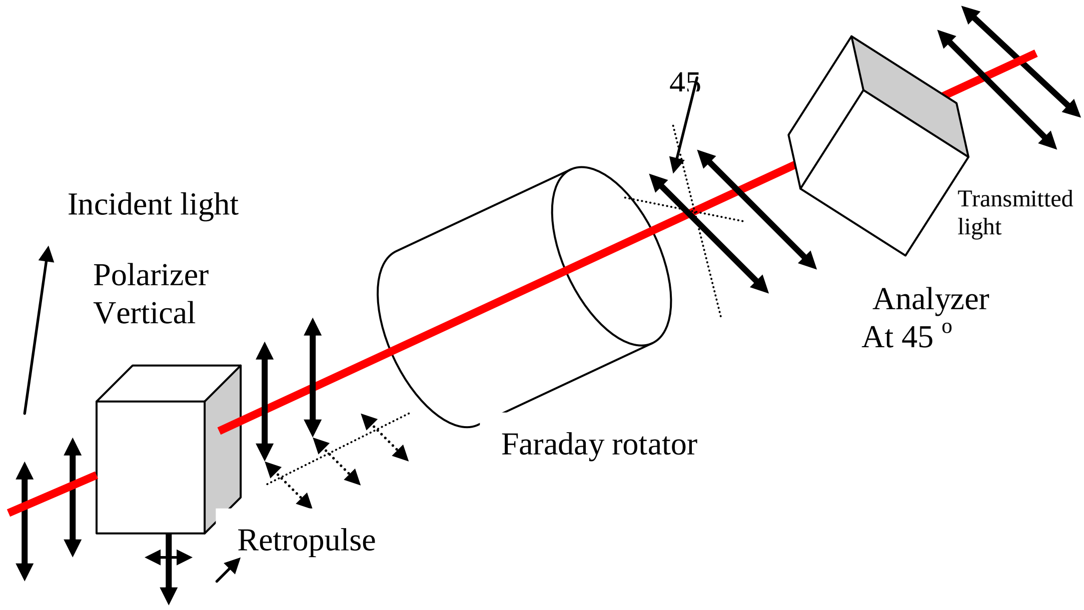


Fig. (2.26): The Faraday rotator used as an optical isolator (redrawn from Frank).

2- The Faraday Effect can be used to analyze mixture of hydrocarbons, so each component has its magnetic relation (Lipson 1995).

3- The magneto optic device mostly used in large capacity computer memories (Wilson and Hawakes 1983).

4- Kerr effect can be used as a shutter in high speed photography and as light beam chopper to replace rotating toothed wheels and used to measure the speed of light (Zajic 1987).

5- Kerr cell can also be used for Q-switching of pulsed laser system (Mikirtychev, 1997, Frank 1996 and Zajic, 1987).

6- Pockels cell can be used as ultra fast shutters, Q –switches for lasers, high modulator, and D.c field to 30-GHz light modulator (Zajic, 1987).

7- Pockels cell can be used as a cavity dumper by applying half wave voltage; it rotates the linear polarized laser beam to be dumped by the polarizing prism as in Fig. 2.27 (Frank, 1996).

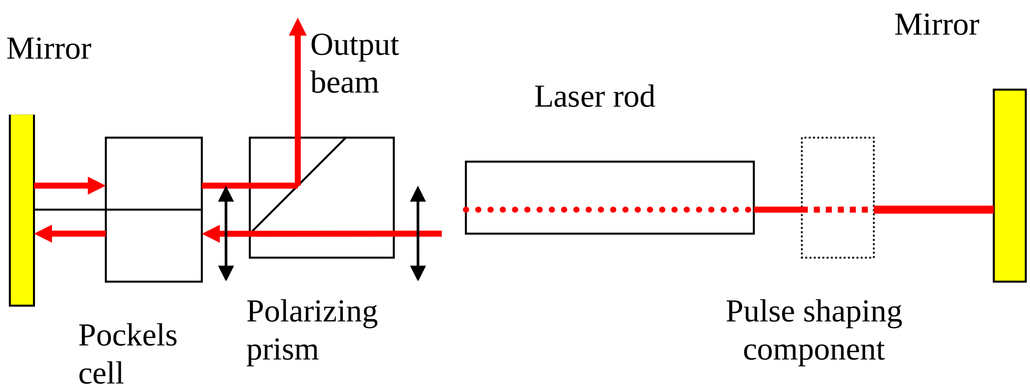


Fig. (2.27): The Pockels cell used as a laser cavity dumper.

8- The acousto-optic (AO) effect can be used to control the amplitude, and frequency of the modulated light beam (Wilson and Hamakes, 1987 and Frank 1996).

9- Acousto-optic system can be used for measuring the spatial light intensity distribution (Robert, Fieget, Hays and Wright 1989).

10- Amplitude modulation and phase fluctuations can be used to monitor propagation and focusing of light power laser beams without distortions (Baida and Zhang, 1997).

11-Acousto-optic device can be used as spectrum analyzer (Frank, 1996).

12- Acousto-optic device is used as abeam deflector to initiate laser cavity dumping, so when no acoustic wave is applied, the beam (1) as in Fig. 2.28 swings back and forth in the laser cavity and rising the energy to maximum, and when acoustic wave applied, then the beam (2) deflected out of the cavity, dumping the energy stored in the cavity (Frank, 1996).

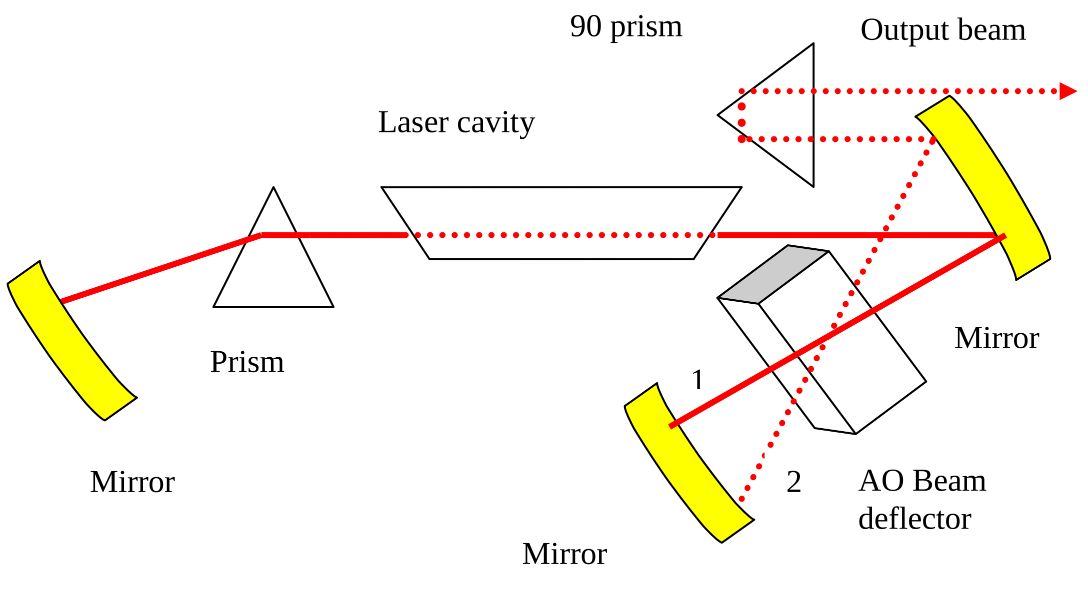


Fig. (2.28): Cavity dumping of a laser using acousto-optic (AO) beam deflector (redrwan from Frank).

13- The optical activity is used in industry, such that sugar concentration can be measured by measuring the amount of rotation of light produced when a beam of light is passed through (Nussbaum and Phillips 1976).

14- The Kerr effect has been used in electro-optic shutter to measure the speed of light (Nussbaum and Phillips 1976).

Chapter Three

Eperimental system and circuitry construction

3.1-Introduction:

This chapter deals with the experimental part of the work that will cover the folowing topics. The experimental setup, which describes the tools and apparatus used. The system is composed of three main parts. The He-Ne laser, the modulation units and the detection circuit. The laser is connected to a measuring electronic equipment for signal processing. (Quality assurance) Authentication then will follow to prove the credibility of the system for transmitting information and detecting changes in the beam vicinity at different frequency ranges.

3.2- Laser beam modulation using sound speaker:

Laser light can be modulated by any one of the previous optical modulation techniques (see chapter two). Laser light is characterized by a high degree of spatial coherency and high beam directivity this gives the ability to focus the laser beam into small spot diameter with relatively large depth of focus (Blat, 1992). The laser output power are usually pictured as a continous beam having constant power. For laser communications and other scientific applications the beam need to be changed, i.e. modulated, in a controlled manner. This modulation can be used in the form of amplitude modulation (AM) which changes the level of detected power of the beam, or frequency modulaion (FM) which changes the frequency, or color of the beam. Such modulation adds information to the beam, that can be carried by the beam and transmitted to a distant location, where it can be extracted and used. For example, a telephone conversation can be encoded in a modulated laser beam and sent across the united states or undersea to Europe or Asia, where the convesration is decoded and heard as a spoken voice. Modulation speeds of greater than (10 to 100 GHz) with rises times in the range of picoseconds have been demonstrated.

To derive the vibration modulation using sound speaker, assume a light wave advancing from left to right as shown in Fig. 3.1, the amplitude (A) distribution (Meyer-Arendt,1984) can be given:

$$A = A_{ro} \sin(\omega t) \qquad (3.1)$$

where A_{ro} unmodulated amplitude.

If the wave is allowed to fall on a plane mirror vibrated at the speaker's diaphragm frequency to which it is glued, the amplitude distribution (A_r) of the reflected wave toward the detector can be described:

$$A_r = A_{ro} \sin(\omega t + \Phi) \qquad (3.2)$$

where $\Phi = (\phi_I + \phi_s)$, where ϕ_I is the phase differnce inherent in the light wave and ϕ_s is the phase differnce imposed on it as a result of vibrating the mirror. Squaring both sides of equation (3.1) to get the intensity distribution (I) at the detector:

$$I = I_o \sin^2(\omega t) \qquad (3.3)$$

By using the identity $\sin^2 \theta = \frac{1}{2}(1 - \cos 2\theta)$ and $\omega = 2\pi f$, then equation (3.3) is

$$I = \frac{I_o}{2}\left(1 - \cos(4\pi f_s t)\right) \qquad (3.4)$$

where f_s is the speakers vibration frequency, therefore the intensity of the laser is modulated at the speaker's vibration frequency.

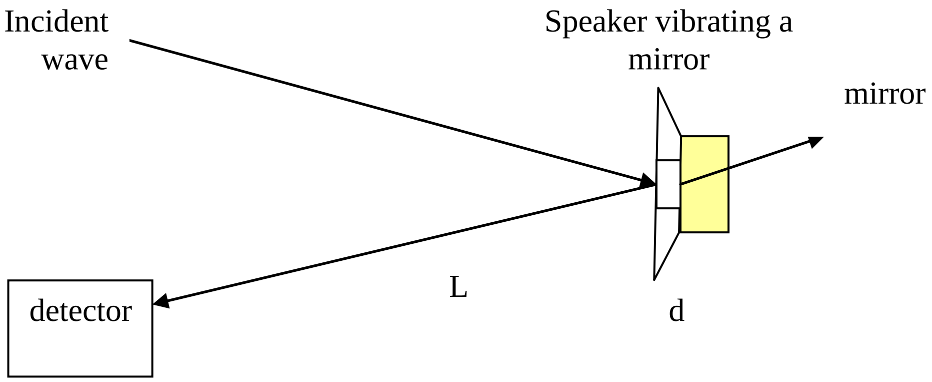


Fig. (3.1): Schematic of basic components used in mirror vibration modulation.

3.3- Experimental system:

The basic experimental setup used in this work is shown is Fig.(3.2) below:

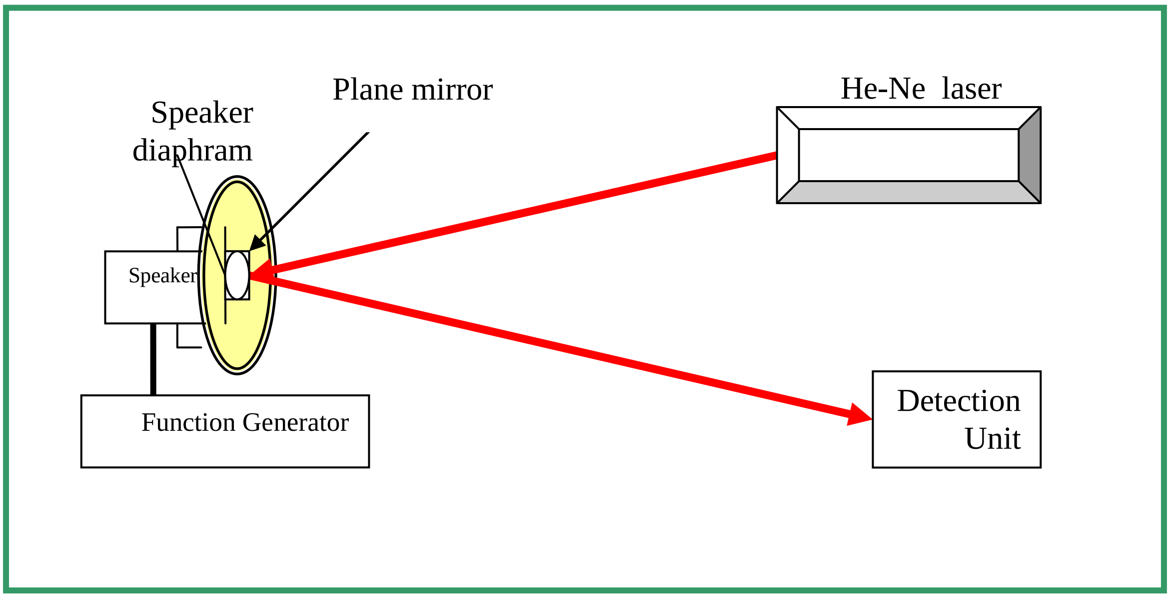


Fig (3.2): Schematic showing spaital intensity modulation techniques using sound speaker.

As seen from the experimental setup, the laser beam incident from the source on a plane mirror glued to the diaphargm of a speaker reflected to the detection unit. The plane mirror will vibrate at the same speaker's frequency. Laser light is allowed to fall on a photo electric device that converts the modulated beam into an electric current. This current signal is then amplified and the sound wave can be heard at the speaker's frequency. When light hits the photo-electric device, photon energy is absorbed in the depletion layer generating hole and electron carriers, and is then connected as current at the electrodes before recombination. This current is fed into an electric circuit for further processing of filtration and amplification before information can be retreived in the required form.(see Fig. 3.3).

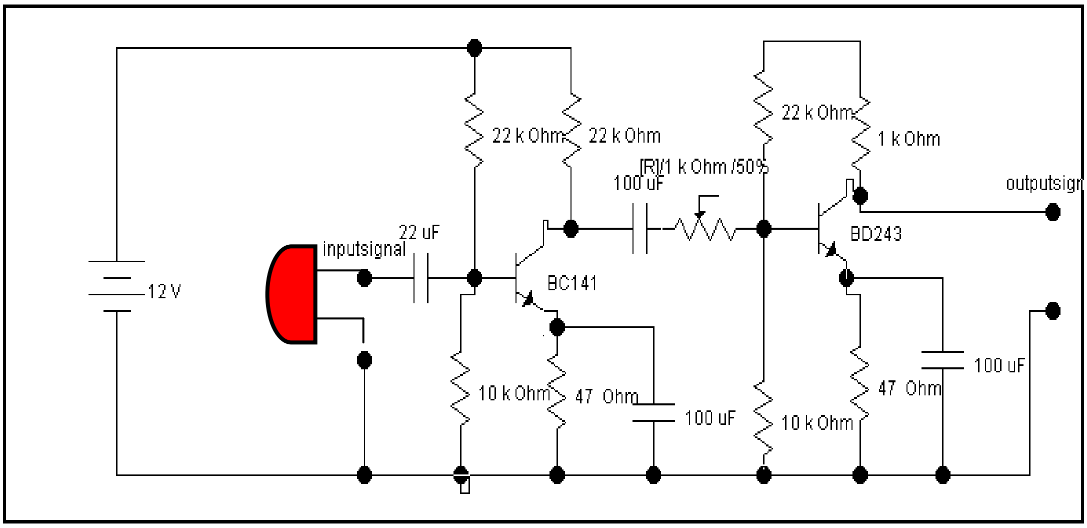


Fig.(3.3): Schemetic showing the detection circuit(Keishi,2001).

As seen from Fig. (3.2) the modulated laser beam signal is allowed to fall on to photo-electrical device (type BPX 381) a planner silicon photodiode housed in case hermetically sealed with an integral plain glass window. The cathode is electrically connected to the case, the device has low junction capacitance, short switching time and capable of detecting wide band width frequency signals, application include alarm systems, light fluctuation and speed pulse detection. The electronic signal is then fed to the first filter and to the first amplifier and will be processed in the second circuit as before.

3.3.1- He-Ne Laser:-

In February of 1961, Ali Javan and his associates Bennett, and Harriett had reported the successful operation of a continuous wave He-Ne laser (Zajic, 1987). The He-Ne laser consists of a glass tube filled with a mixture of helium and neon gases, a means of creating discharge by applying a d.c. field through the internal electrodes or by applying external radiation microwaves (Hollas, 1996), and end mirrors to form the resonant cavity, that are outside the plasma tube as in Fig. (3.4).

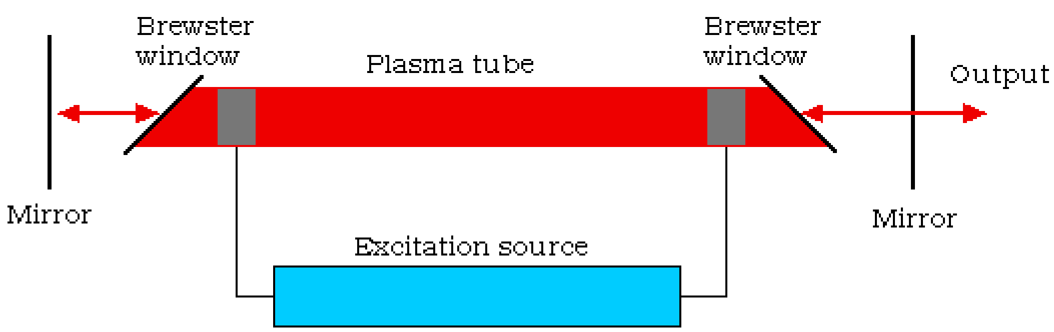


Figure (3. 4) The schematic diagram of a He-Ne laser.

Helium atoms are "pumped"up to excited states by electrical discharge through electron-atom collisions in a discharge tube. The energy transfer by collision to neon atom and elevates neon atoms into a metastable state, so the neon atomes are emitting radiation (see Fig. 3.5)

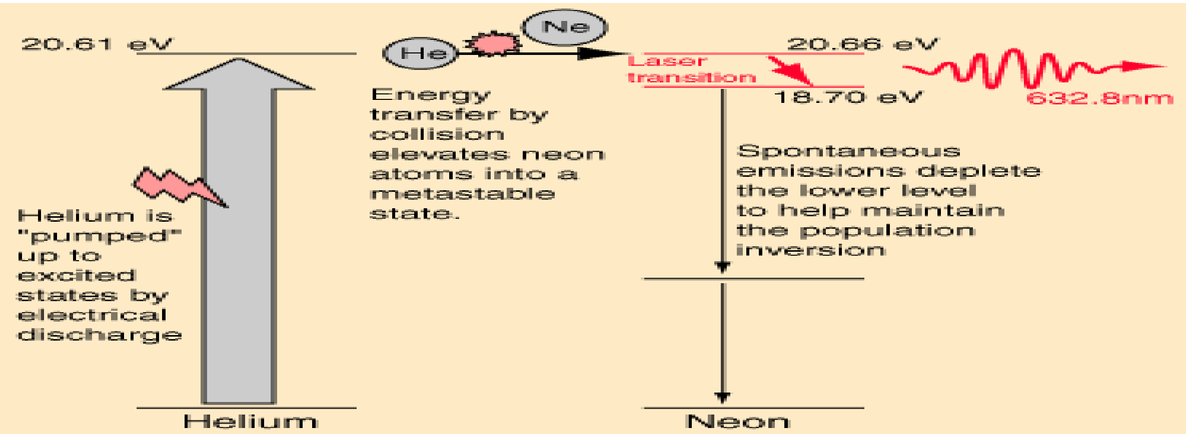


Fig. (3.5): The excitation of helium atom and the transition energy of neon atoms (redrawn Zajic).

Figure (3.5) shows a simplified atomic energy levels diagram, showing exited states of atomic He and Ne relevant to the operation of the He-Ne laser at 6328 A^{o}, and energy levels in Neon depicting the laser transitions.

He-Ne lasers that are now available cover wavelengths in the infrared at 1523 nm, visible and ultraviolet regions (Serway, 1992). The He-Ne laser is usually constructed to operate in the red at 632.8 nm, and it can also be constructed to produce laser action in the green at 543.5 nm and in the infrared at 1523 nm. He-Ne laser is known for its high frequency stability, color purity and minimal beam spread.

3.3.2- Modulation Unit:-

The Modulation unit is basically formed of an ordinary sound speaker. The speakers properties are 70-watt power and 4-Ω impedance. The speaker is operated with a function generator that can be swept at frequencies 1 to 100 KHz, so its diaphragm will vibrate at the generator range of frequencies. A square plane mirror of two centimeters width was glued to the center of speaker diaphragm with silicon rubber glue.

3.3.3-Detection of modulated light beam

3.3.3.1- Circuit and components

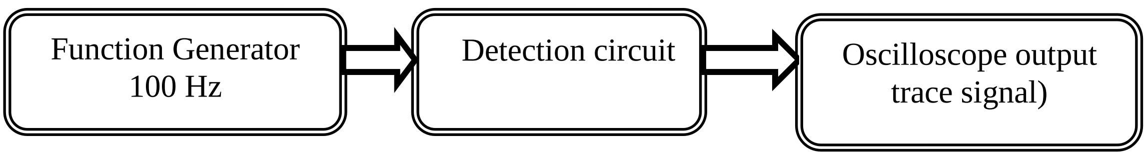
Refer to Fig. (3.3) which shows the detection circuit used in this work. The list of components are as follows:

- Resistances: The circuit contain eight resistances (three 22 kΩ, two 10-kΩ, two 47-Ω, and one 1-kΩ) are connected in the circuit shown in Fig 3.3.

- Blocking capacitor: the circuit contains four blocking capacitors three have capacitance of 100-μF and the forth has 22-μF.
- Potentiometer (R): The resistance of the potentiometer is 1-KΩ, it joins the two sides of the translation and amplification sides of the circuit.
- Transistors: The circuit employs two different transistors: the first one: type BC141, has n-type property, 3.7-watt, 80-U_c, 40-U_{CE}, I_C = 1 Ampere, B(β) = 63-160, and the frequency f_r = 50 MHz. The second one:type BD245,N-type ,80-watt,45-U_c, 45-U_{cE}, I_c = 10 ampere, B(β) >12).
- Voltage source: a source capable of 12 volts DC.

3.3.3.2-Construction of thedetecting circuit:-

The relevant circuit was first drawn on an A4 sized paper. The interest is to build up the curcuit on a special curcuit board easy to handle the detector of the modulated laser beam. The drawn circuit is then photocopied on a transparent sheet and imposed on the circuit board with an upper copper layer. The baord then immeresed in acid and then relevant circuit etched chemically. Electrical components are then soldered in place. Then circuit checked for proper connection using a digital multimeter. Post check is carried out by feeding in a 100 Hz from a function generator and the output trace displayed for amplitude and frequency check. Any deviation from the correct frequency will be compensated using the potentiometer(See Fig. 3.6).



Figuer (3.6): Schematic showing arrangment of post test for detection circuit.

3.3.3.3- Detection of the modulated beam:

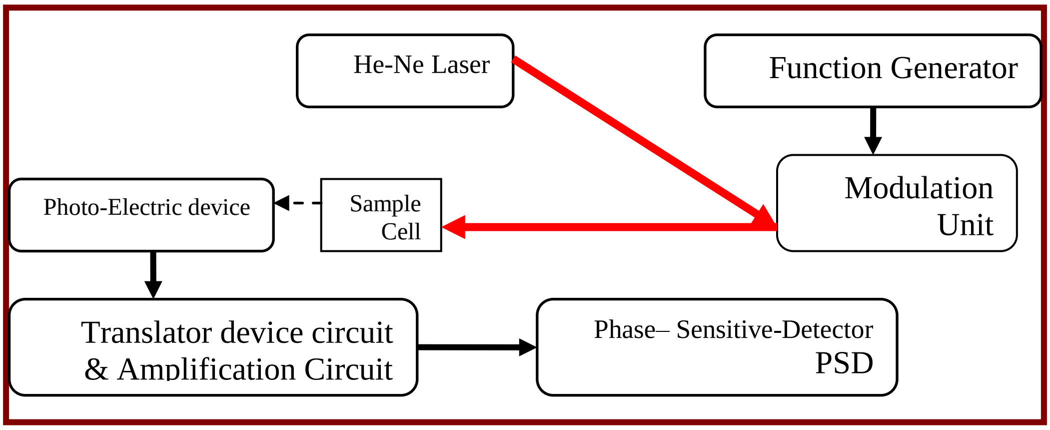


Fig. (3.7): Schematic showing block diagram of the complete experimental system.

An experimental investigation was performed using a He-Ne laser source at optical wavelength $\lambda = 632.8$ nm (155 laser 115-220 V,0.5-0.25 A). The laser beam incident on the modulation unit, fig.(3.1), the reflected beam is allowed to fall on photo electric detector type BPX 381 connected to the detection circuit, an output of which is fed through phase sensitive detector (PSD) which is used to process the light signal that falls on photoelectric detector and convert it into electrical signal.

3.4- The experimental method:

The complete experimental system is shown in fig.3.7. Laser is reflected from the modulation unit and passed through the sample under ivestigation placed in a cell and then allowed to fall on the detection unit where it is processed and analyzed for the information needed depending on the type of measurement. Sample cell is changed according to the nature of application involved. In chapter 4 details of experiment together with experimental results will be given using mainly the set up shown in this section.

Chapter Four

Experimental Results

4.1- Introduction

Beam modulation methods have seen an increasingly wide range of application. The aim of this experiment is to investigate many possible applications employing modulated laser beam. In this work the apparatus was arranged as shown in a block diagram of the optical system Fig.4.1. Light from a He-Ne laser (type-155 model), delivering a light of wavelength λ = 632.8 nm. At the beginning many runs were performed to understand the system, its stability and, the best operating conditions. The range of frequencies to which the system is most sensitive was studied (see Fig. 4.2). It is found that the detector has a good response over the range of 10–18 kHz, with the best detecting ability at ~ 17 Hz. Most experiments were carried out on a fixed modulation frequency 17 Hz, which has the best detecting sensitivity. Moreover, it is advisable to choose frequency that is not close to the vibrating machinery operated using the AC frequency of 50-KHz.

Fig. (4.1): Photograph of the system.

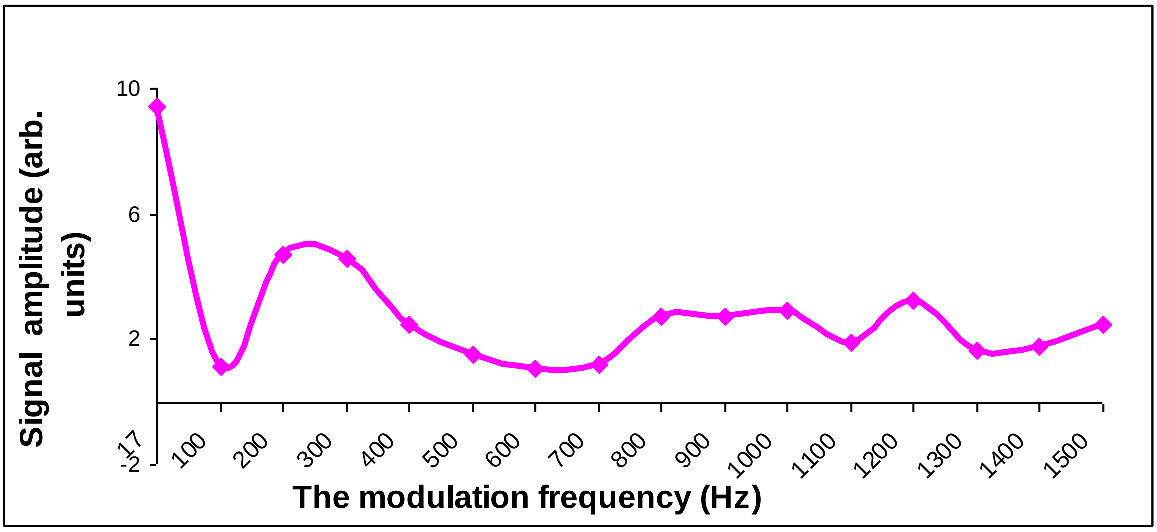


Figure (4.2): The detected signal amplitude (arb. units) versus the vibrating plane mirror frequency, which was set at constant vibrating amplitude of 0.5 Volt.

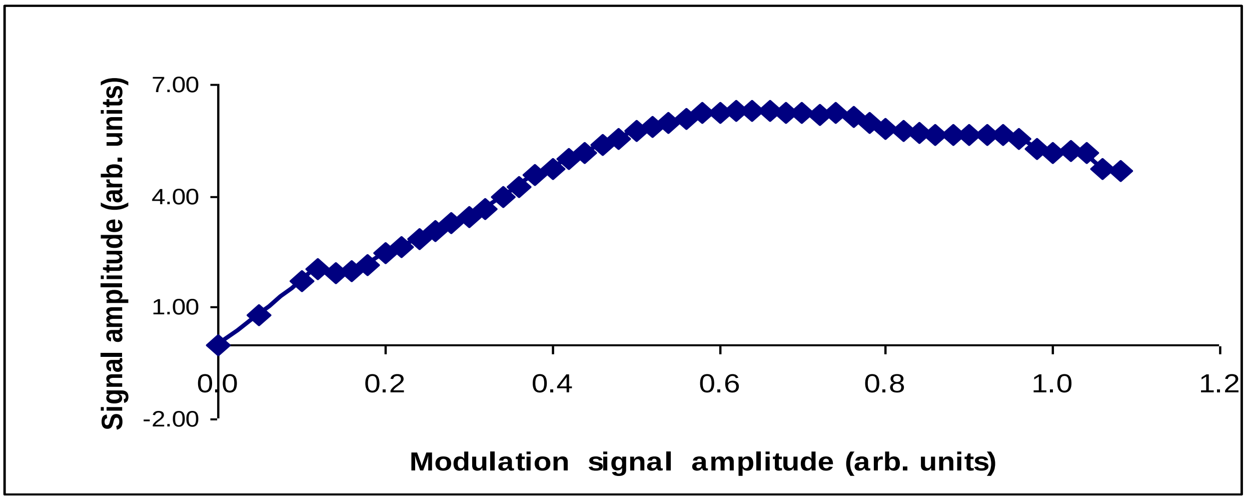


Figure (4.3): The detected signal amplitude (arb. units) versus the vibrating plane mirror amplitude (arb. Units),which was set at a constant vibration frequency ~ 17-Hz.

4.2- System testing and authentication:

Figure 3.1 shows the experimental arrangment for most applications. The input signal from a function generator applied to 4-Ω impedance speaker results in the vibration of a small plane mirror glued to the speaker's diaphram (see Fig. 3.2). The reflected laser beam is then modulated at the same vibration frequency of the mirror. A simple test was carried out by connecting the speaker vibrating the mirror to be part of a sound recorder. The detector and corresponding circuit was connected to another speaker. When sound recorder is played the song is heard with a good sound quality at the distant speaker connected to the detector, i.e the system transfered sound from place to another at the speed of light. The second test aimed at investigating the ability of the system to transfer information over the range of possible frequencies. Two trials were attempted; the first was to test the ability of intensity modulation of the laser beam over a range of frequencies 10–18 KHz employing the method suggested in this work, Secondly the laser beam was chopped using a mechanical chopper, i.e amplitude modulation and the results of both methods compared.

Vibrating mirror frequency (f_1 Hz)	The Detected modulation frequency (f_2 Hz)	The mechanical chopper (f_2 Hz)
10	10	10
20	20	20
30	30	30
40	40	40
50	50	50
60	60	60
70	70	70
80	80	80
90	90	90
100	100	99.5
150	150	149.5
200	198.5	199.5
250	248.5	249.5
300	298	298.5
350	347.5	347.5
400	397	398.5
450	447	448
600	546.5	498.5
650	646.5	548
700	696.5	596.5
750	746	647.5
800	795.5	746
850	845.5	846
900	894	895.5
950	945.5	945.5
1000	994.5	995
1250	1238	
1500	1486	
1750	1734	
2000	1985	
2500	2480	
3000	2975	
3500	3470	
4000	3975	
5000	4975	
6000	5960	
7000	6950	
8000	7960	
9000	8950	
10000	9955	
11000	10930	
12000	11930	
13000	12860	
14000	13900	
15000	14890	
16000	15920	
17000	16850	
18000	17910	

Table (4.1): Shows the input signal frequency by the vibrating mirror and mechanical chopper and the detected frequency (output frequency).

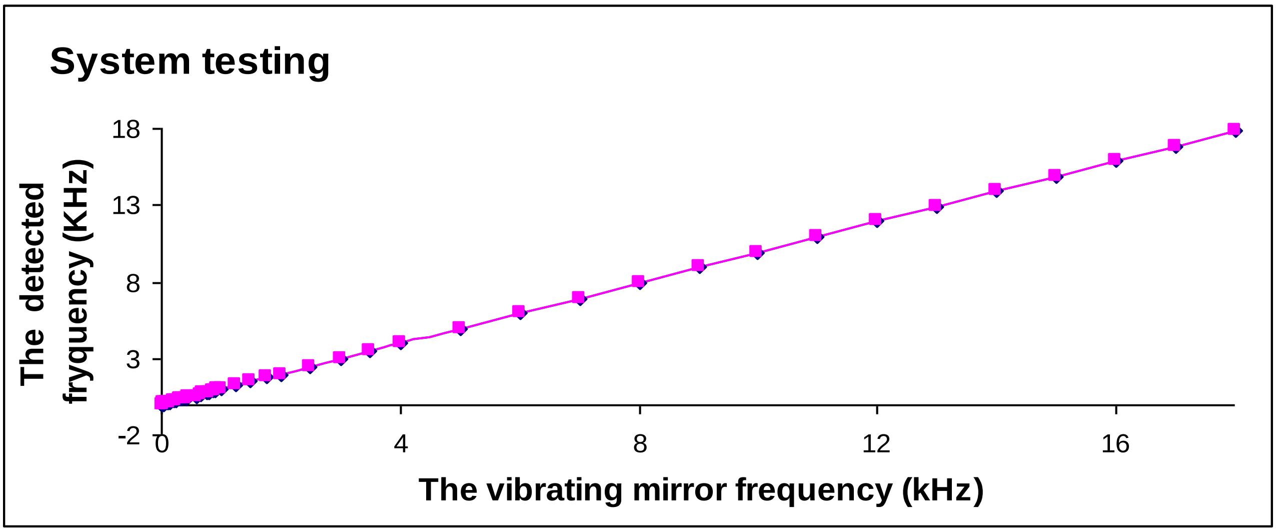


Figure (4.4-a): graph showing the frequency of vibrating the mirror vs detected frequency.

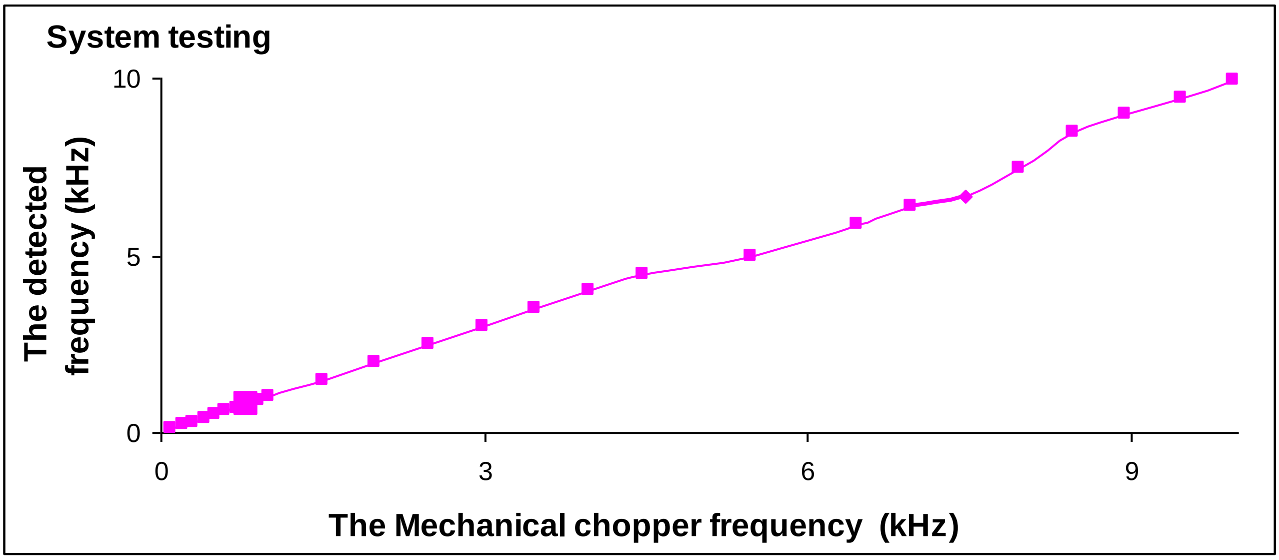


Figure (4.4-b): Amplitude modulation frequency of He-Ne beam vs the detected frequency.

4-3- Some applications of laser beam modulation:-

There are many applications that can be carried out using laser beam modulation. In the present work efforts made to try many possible applications to prove the ability of this simple method. In all trials to come the modulation frequency was set at 17 Hz and modulation voltage ~ 0.5 volt unless otherwise stated.

4.3.1- Food quality control:-

a- Orange juice concentration:

In this experimental test the orange juice liquid was used as a sample. An orange juice sample 20-cm^3 was diluted by adding in steps of 2-cm^3 of drinking water each time up to 20-cm^3, i.e. when the ratio becomes 1:1 by volume of water to juice. The laser source was placed at 26 cm from the vibrating mirror and the curette (sample cell) at about 4 cm from the photo electric device and about 168-cm from the vibrating plane mirror. The detected signal amplitude for different orange juice concentrations was given (See table 4.2 and Fig. 4.5).

Volume of added water to 20 cm^3 orange juice sample	The detected signal amplitude (arb units)	Volume ratio concentration (%)
0	-1.05	1
2	-0.27	0.91
4	0.33	0.83
6	0.65	0.77
8	1.59	0.71
10	2.59	0.67
12	3.05	0.63
14	3.48	0.59
16	4.49	0.56
18	4.89	0.53
20	5.58	0.5
22	6.22	0.47
24	7.78	0.45
26	8.00	0.43
28	8.61	0.42
30	9.01	0.4
32	9.41	0.38
34	9.46	0.37
36	9.71	0.35

Table (4.2): The detected signal amplitudes through the orange juice sample at different concentration.

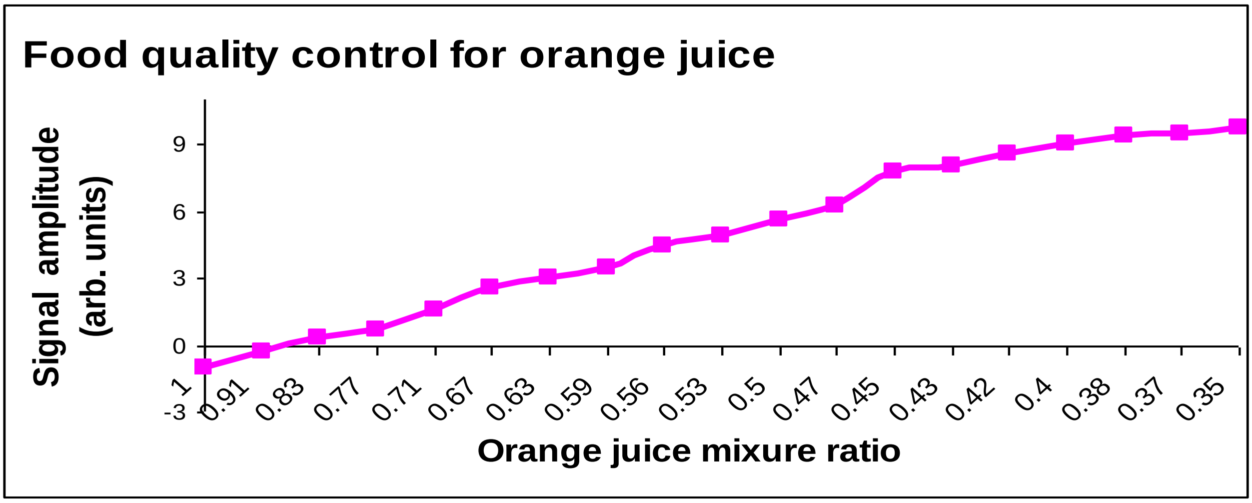


Figure (4.5): The detected output signal amplitude versus orange juice volume to mixture ratio taken at constant modulation frequency ~17-Hz.

b- Olive oil storage conditions:-

This part of experiment was aimed at studying several samples of olive oil from different production years, which was stored or kept in a plastic and glass bottles in the dark. The ability of the system to distinguish different vegetable oils such as olive oil, black cumin and sunflower oil was also investigated.

	The detected signal amplitude (arb. units)			
	Olive oil (Aseera - Nablus) was kept in plastic bottles.			
Modulation Frequency (Hz)	Olive oil (1994)	Olive oil (1995)	Olive oil (1996)	Olive oil (1998)
10	4.71	10.23	10.23	9.46
13	3.66	10.23	10.23	7.44
17.5	2.49	5.04	4.91	2.39
20	-0.63	-2.62	-2.61	2.73
23	4.12	4.03	5.06	6.5
26	3.93	4.2	4.55	5.17
30	1.4	2.97	2.22	2.14
40	-4.37	-4.81	-4.55	-7.47

Table (4.3): The Detected signal amplitude through different samples of olive oil at different modulation frequencies

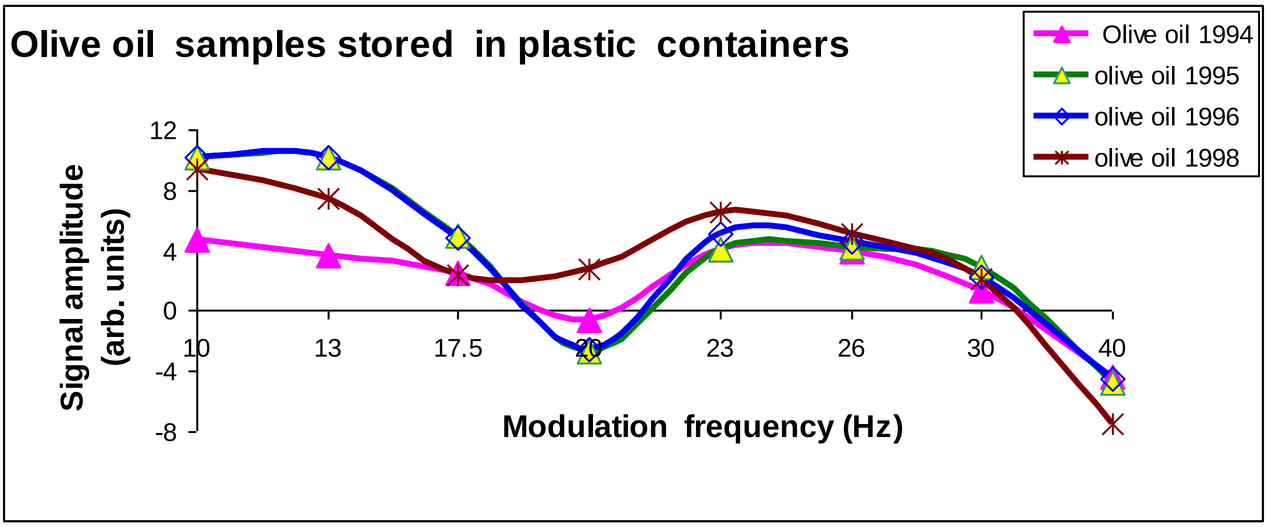


Figure (4.6): Signal amplitude versus the modulation frequency, for four olive oil samples different production years, kept in plastic containers.

	The detected signal amplitude (arb. units)			
	The oil (Aseera oil - Nablus) was kept in glass bottles			
Modulated Frequency (Hz)	Olive oil (1995)	Olive oil (1996)	Olive oil (1998)	Olive oil (1999)
10	10.23	10.23	10.23	10.23
13	10.23	10.23	9.02	10.23
17.5	3.15	3.22	2.94	4.91
20	4.42	4.58	3.45	0.43
23	7.91	8.52	7.65	6.28
26	6.55	6.13	6.05	4.87
30	2.8	2.26	3.14	2.14
40	-7.13	-7.79	-7.63	-6.28

Table (4.4): The Detected signal amplitude for different samples of olive oil at different signal frequency, and constant amplitude ~ 0.5 volt.

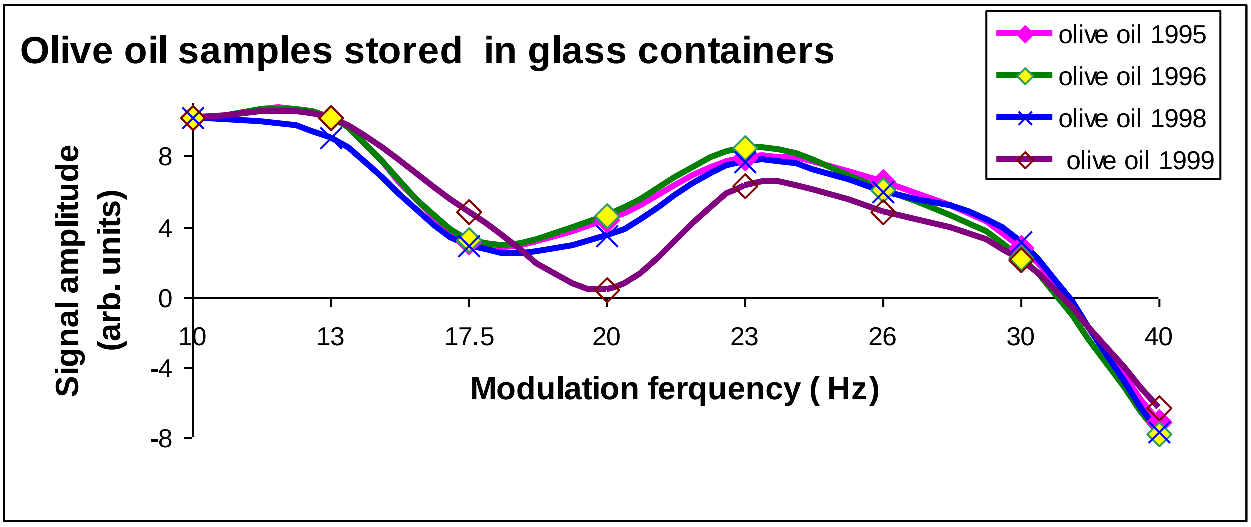


Figure (4.7):- The detected signal amplitude versus the modulation frequency for different olive oil samples stored in glass containers.

	Detected signal amplitude (orb. units)		
	Different oil Samples		
Modulation Frequency (Hz)	Black cumin oil 1996	Olive oil 1996	Vegetable oil 2003
10	6.42	8.14	10.23
13	4.61	6.6	9.92
17.5	0.95	1.54	2.79
20	-0.29	-0.52	-0.73
23	1.72	3.13	3.82
26	1.5	2.51	1.68
30	0.18	1.63	0.44
40	-2.49	-4.1	-5.15

Table (4.5):- Detected signal amplitude for different oils at different frequencies.

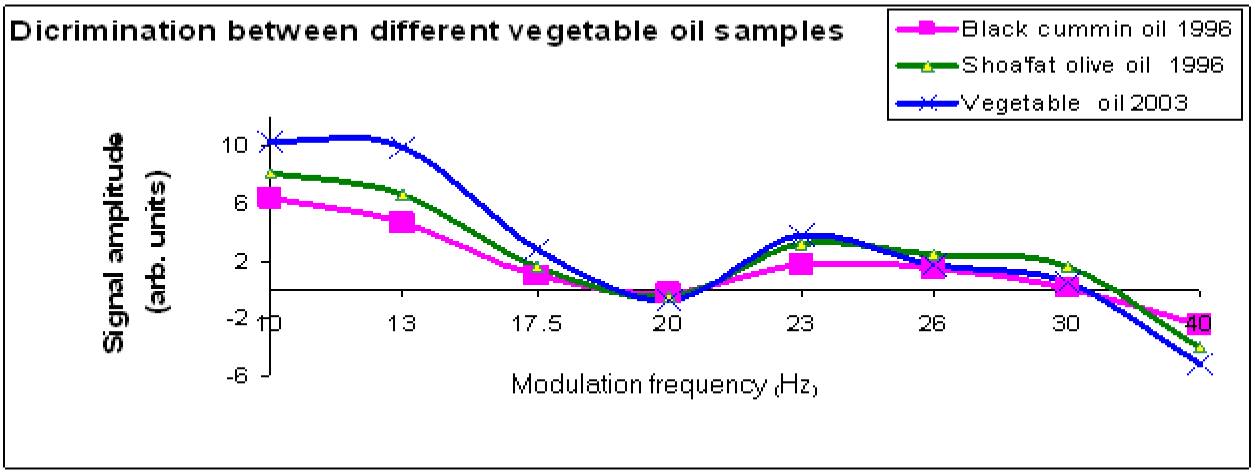


Figure (4.8):- The detected signal amplitude versus the modulation frequency through different types of vegetable oil samples.

4-3.2- Solution concentrations:-

A- Measurements of salt concentration:-

The same procedure of section 4.3.1 was repeated for salted liquids at different concentrations. Different salt liquid concentrations were prepared by adding 2-grams each time of salt to fixed 200-cm^3 of drinking water. The laser source placed at 31-cm from mirror 120-cm from the cell while the distance between the cell and the photo electric device is 5-cm, water temperature is 24 ^oC. The detected signal amplitude for different salt liquid concentrations is shown in table 4.7 (See Fig. 4.9).

Salt concentration gm / cm3	The detected signal amplitude (arb. units)
0.000	8.01
0.010	7.95
0.020	7.22
0.030	6.83
0.040	5.75
0.050	5.30
0.075	5.03
0.100	4.00
0.125	3.44
0.150	2.70
0.200	2.45
0.250	1.40
0.300	0.79
0.350	0.15

Table (4.6): Detected signal amplitude (arb units) versus salt concentration.

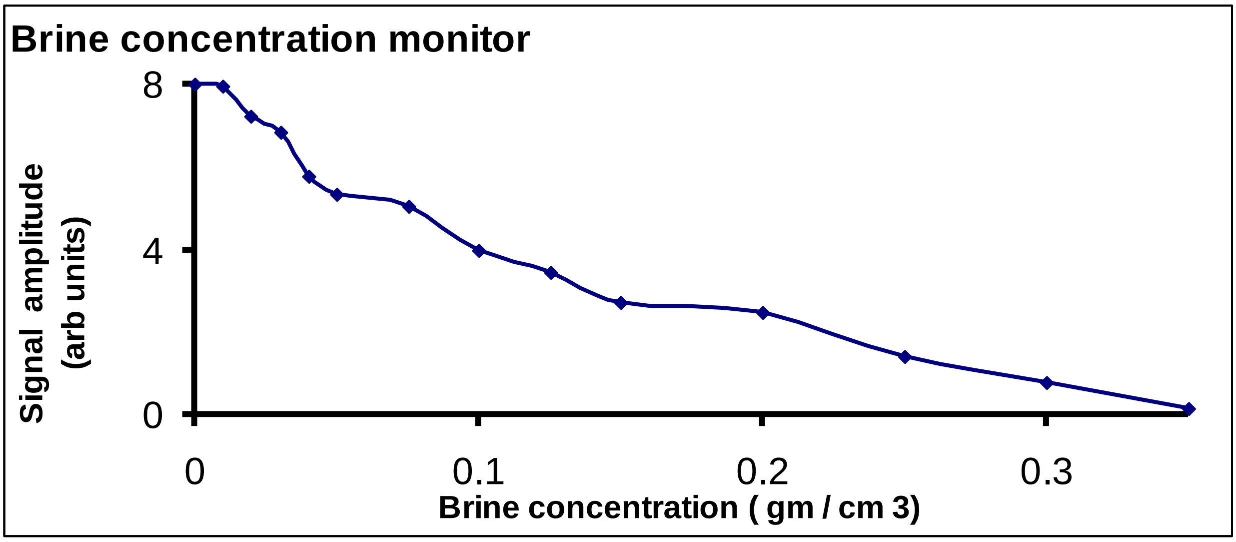


Figure (4.9): The detected signal amplitude versus the concentration of salt solutions results taken at constant frequency ~17 Hz.

B- High sugar concentration:-

Different system sugar concentrations were investigated following the same procedure as given in the previous section. The detected signal amplitude for different sugar liquid concentrations is shown in table 4.8 (See, Fig. 4.9).

Light intensity (arb. units)	Detected signal amplitude (arb. units)	Sugar Concentration (gram\Cm3)
5.4 (water)	3.25	0.00
4.8	2.51	0.05
4.4	2.21	0.10
4.0	1.99	0.15
3.6	1.61	0.20

Table (4.7): The detected signal amplitude versus sugar concentration.

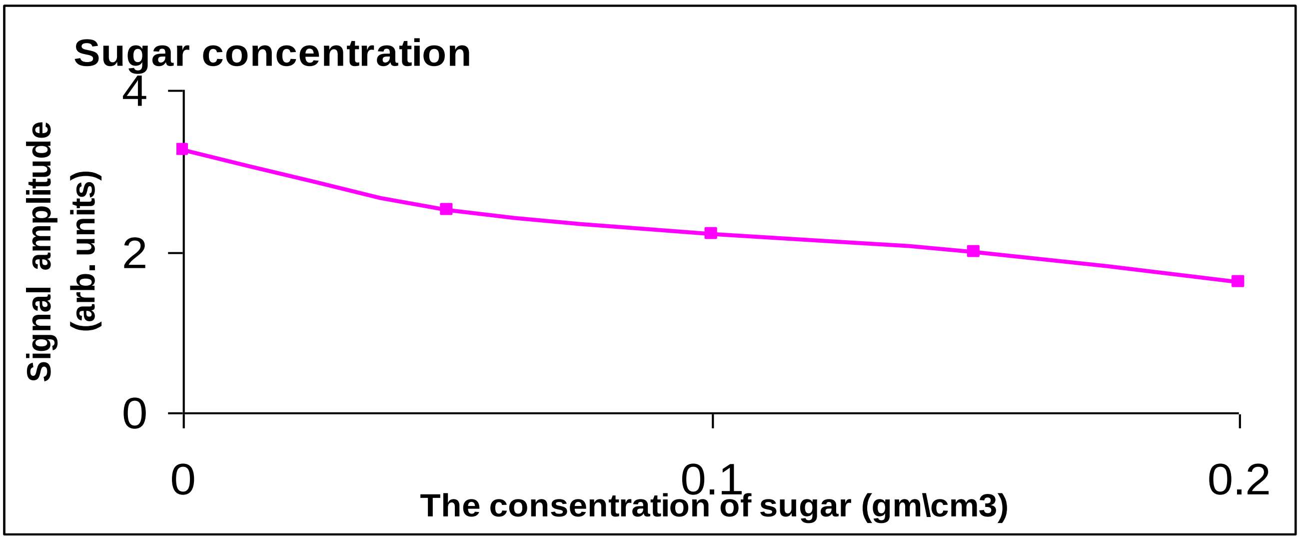


Figure (4.10): The detected signal amplitude versus the sugar concentration.

C-Low sugar concentration:-

Low sugar concentration comparable to those values found in the human blood was prepared. The detected signal amplitudes for different sugar sample concentrations were measured at constant modulated frequency ~ 17-Hz and fixed modulation amplitude = ~ 0.6 Volt are presented in table 4.8.see Fig. 4.11.

The concentration mg/dL.	Detected signal Amplitude.(arb. units)
0.0	9.363
7.5	5.454
15.0	5.067
31.0	5.009
62.5	4.955
125.0	4.987
250.0	5.110
500.0	4.918
1000.0	4.887

Table (4.8-a): The detected signal amplitude versus the law sugar concentration at a constant signal frequency 17 Hz and constant signal amplitude 0.754 volt when the sensitivity of phase sensitive detector is 10 mV.

The concentration mg/dL.	Detected signal Amplitude(arb. Units))
0	3.99
7.5	3.46
15	2.56
31	1.67
62.5	1.47
125	0.88
250	0.6
500	0.42
1000	0.32

Table (4.8-b): The detected signal amplitude versus the law sugar concentration at a constant signal frequency 17 Hz and constant signal amplitude 0.754 volt when the sensitivity of phase sensitive detector is 100 μV.

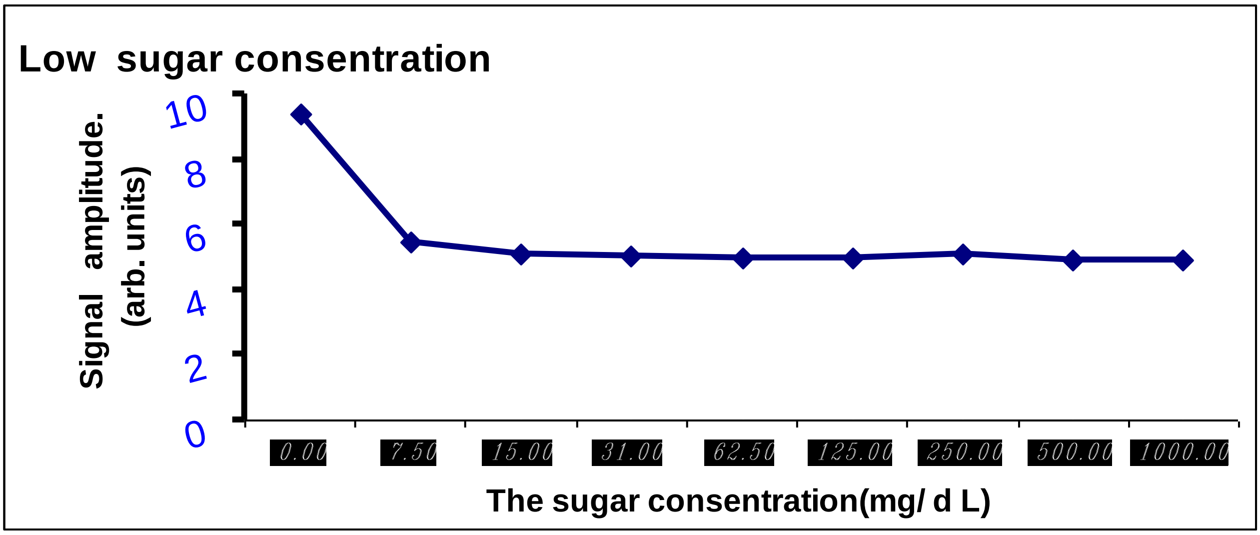


Figure (4.11-a): The detected signal amplitude versus the sugar concentration at vibrating mirror frequency ~17 Hz and constant signal amplitude = 0.754 volt when the sensitivity of phase sensitive detector is 10 mV.

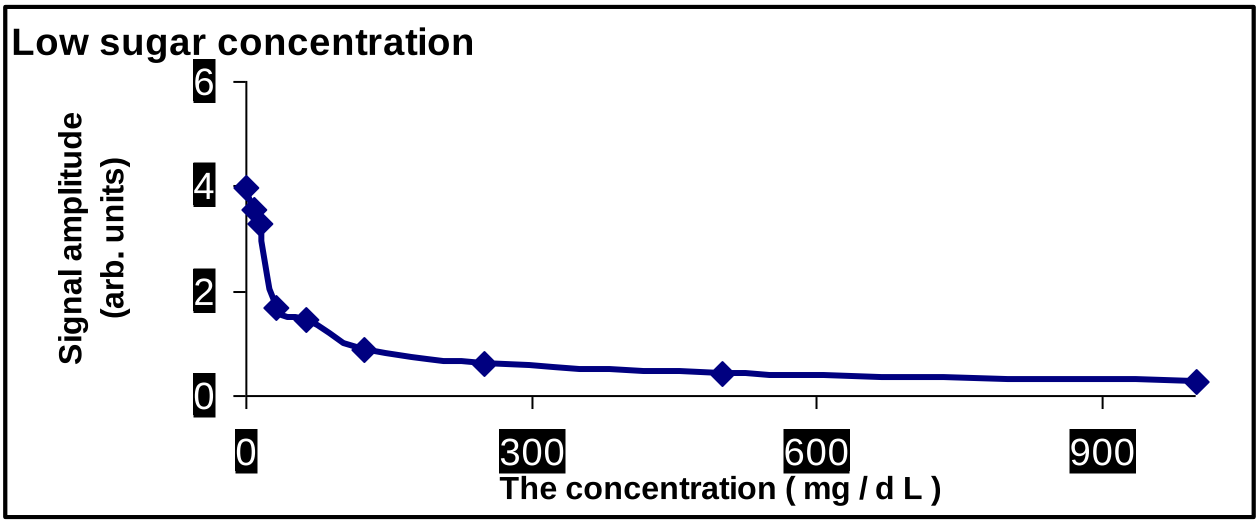


Figure (4.11-b): The detected signal amplitude versus sugar concentration at vibrating mirror frequency ~17 Hz and constant signal amplitude ~0.7 volt when the sensitivity of phase sensitive detector is 100 μV.

4.3.3 Water Turbidity:-

Water turbidity is a measure of water quality and how much it is fit for human use. Certain known standard values are used (Johnson, 1998). Or it is the measurement of water ability to scatter and absorb light (Federal, 2002). Turbidity moments carried out using specially prepared samples by adding a few mg of aluminum oxide (Al_2O_3) to drinking water**.**This material was chosen because it is insoluble in water forming colloid particles similar to turbid water in nature. The detected signal amplitudes that measured by PSD for different sample concentration at constant signal frequency ~ 17-Hz and fixed signal amplitude =0.5 volt are presented in table 4.10 (See Fig.4.12).

Sample No.	Concentration of (Al_2O_3)	Turbidity values (NTU Units)	The detected signal amplitude (arb. units)
1	0.0 (water)		5.46
2	2.2	2	1.41
3	6.3	5	1.174
4	12	10	1.09
5	24	20	1.066
6	64	50	0.98

Table (4.9): The correspondence between the level of colloid particles and detected modulation signal.

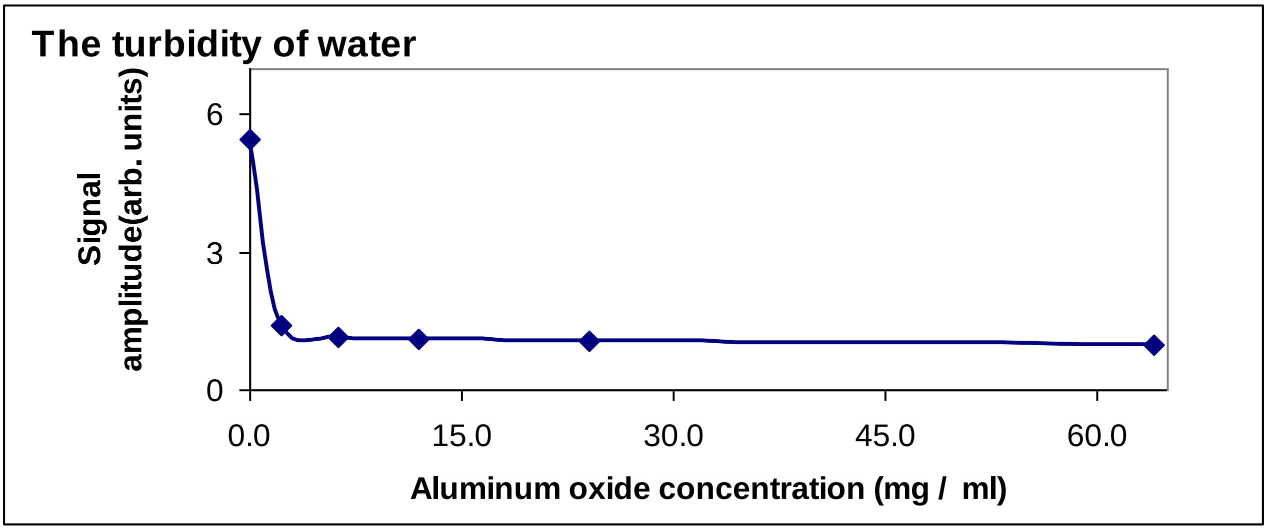


Figure (4.12): The detected signal amplitude versus the concentration of added Al_2O_3 colloid.

4-3.4- Water vapor and smoke detection:-

a- Water vapor:-

Water vapor from a boiling flask was allowed to accumulate in a closed container investigated over a period of time. The importance of this experiment is to check the ability of the system for remote humidity detection. Equivalently the same is carried out for smoke detection. This is rather important for pollution studies in cities or inhabited areas near factories

Time (minute)	The detected signal amplitude (arb. units)
0	8.80
5	7.84
10	6.43
15	5.23
20	4.34
25	3.78

Table (4.10): shows the detected signal amplitude (modulated signal versus the vibrating plane mirror frequency.

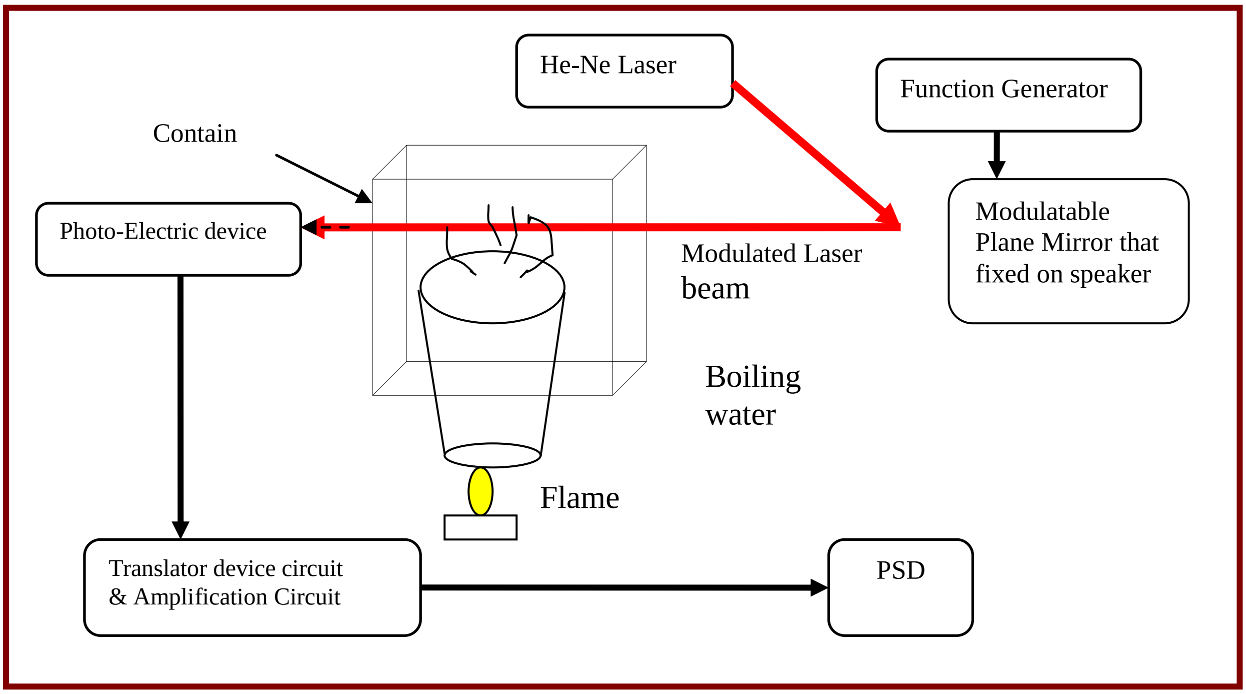


Figure (4.13): Monitor of water vapor accumulation using laser modulated beam.

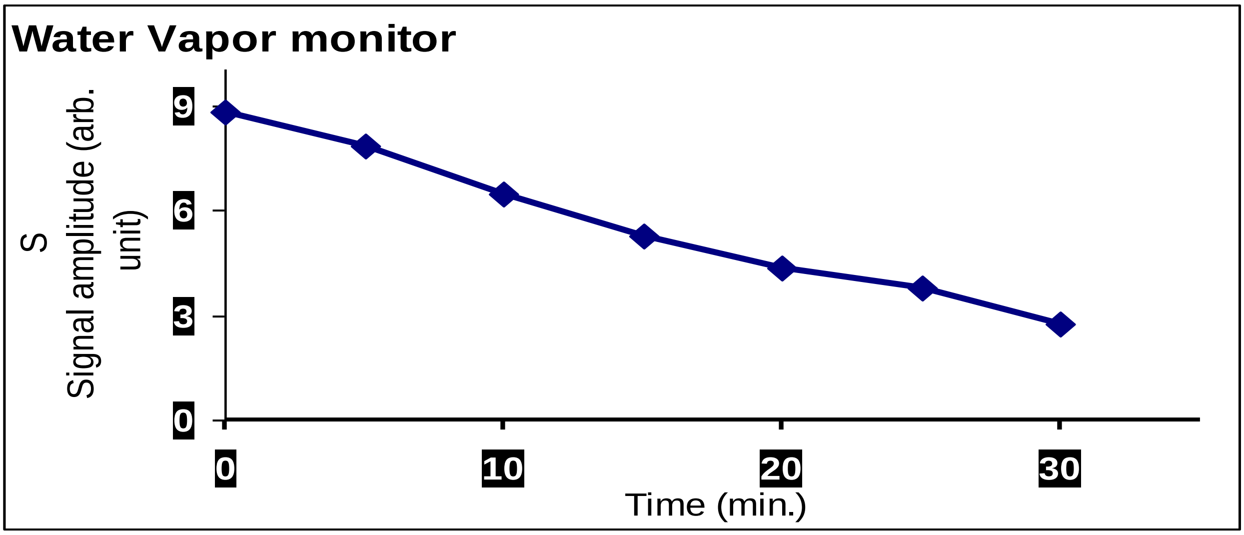


Figure (4.14): The detected signal amplitude drawn against time of water vapor release which allowed cumulating in a container.

b- Smoke Detection:-

In this test, a cigarette smoke was used instead of the water vapor; the same procedure was followed. Signal was detected as time passed and smoke accumulated in the container.

Time Minutes	The detected signal amplitude (arb. units)
0	6.9
1	5.26
2	3.06
3	1.87
4	1.01
5	0.81

Table (4.11): The detected signal through smoke as time poses, at modulated frequency ~ 17 Hz, and signal modulated amplitude kept constant.

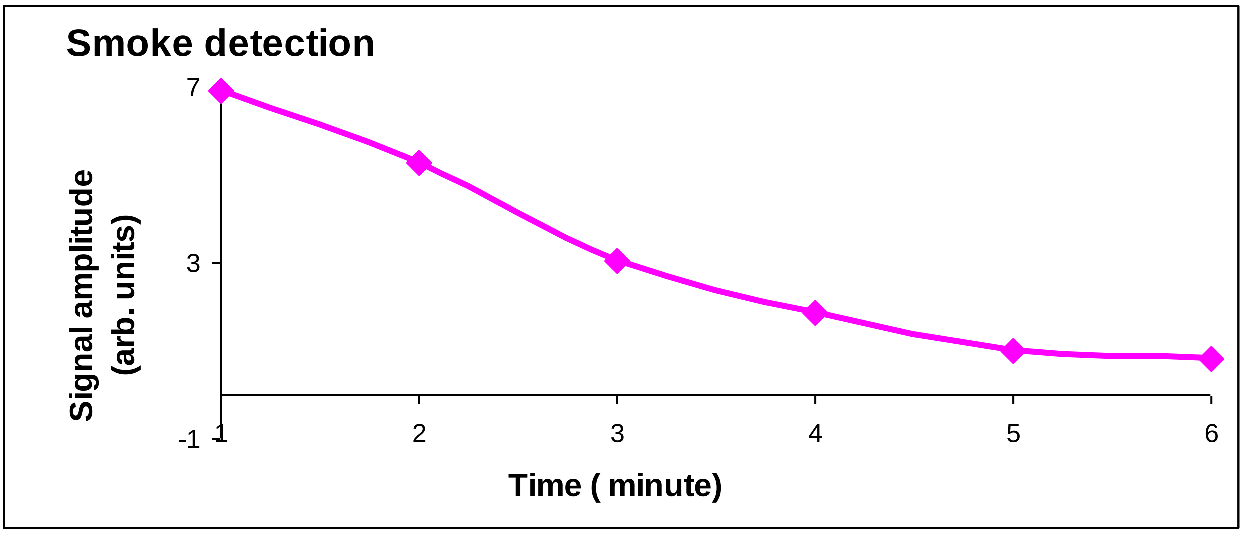


Figure (4.15): The detected signal amplitude drawn against time of smoke accumulation in the container.

4-3.4- Material Thickness:-

Modulated laser beam was allowed to pass through different material thickness. The idea is to establish a control scheme for a factory producing transparent material at certain thickness together with other applications. Glass slabs 0.4 cm thick were added one by one up to 5 of them, results tabulated in table 4.12(See Fig.4.16).

No. Of glass slabs	**Glass slabs thickness (cm)**	**Detected signal amplitude (arb. units)**
1	0.4	6.26
2	0.8	5.34
3	1.2	3.41
4	1.6	2.
5	2	1.98

Table (4.12):- The detected signal amplitude taken at different glass thickness, the modulation frequency ~ 17 Hz at constant modulation amplitude of ~ 0.830 volt.

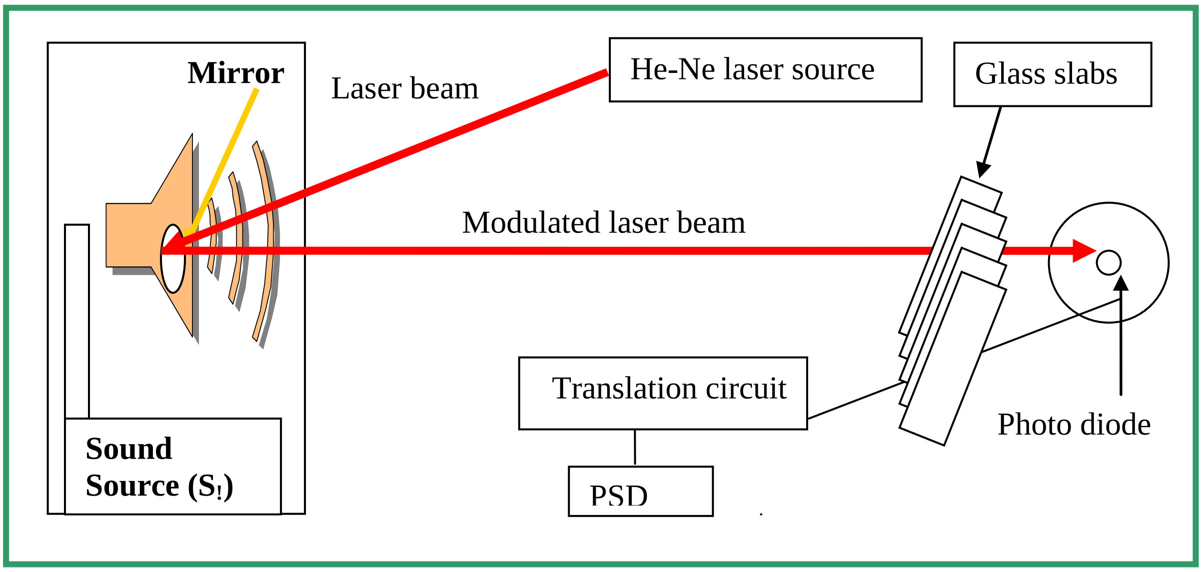


Figure (4.16): schematic showing experimental setup for material thickness detection.

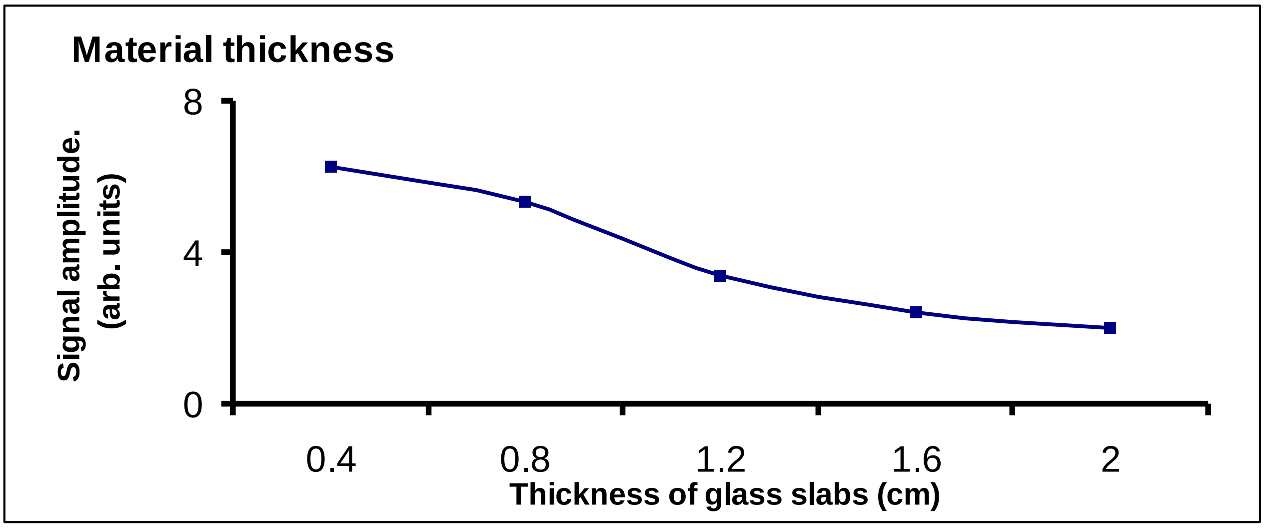


Figure (4.17): The detected output signal amplitude versus the thickness of glass slabs at frequency ~17 Hz

4.3.5- Index of refraction change monitoring:-

The aim of this experiment is to observe the effect of passage of modulated laser light through natural materials of different index of refraction. The samples used in this experiment are, air, water, benzene, glass and Perspex glass. The other procedure of experimental setup is as before.

Material	Index of refraction of the material	Signal output amp. (arb. units)
Air	1.000	8.982
cell(air)	1.238	6.550
Water	1.403	5.500
Benzene	1.486	5.447
Perspex glass	1.510	5.350
glass	1.600	6.200

Table (4.13):- The detected signal amplitude corresponding to different materials at modulation frequency ~ 17-Hz, and constant modulation amplitude of 0.820 volt.

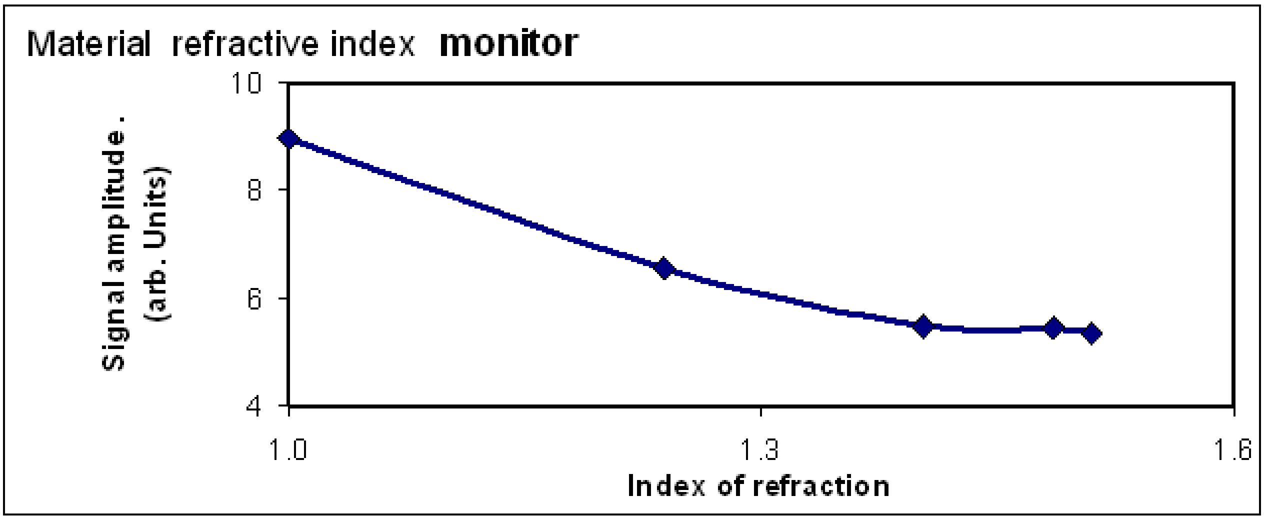


Figure (4.18): The detected signal amplitude through several different transparent materials, at Modulation frequency ~ 17-Hz and constant modulation amplitude ~ 0.8 volt.

4.3.7-Vapor release from materials:-

In this experiment, the signal through vapor released of different materials was detected. One gram by weight of each material was used. It is aimed to study the versatility of the techinque to act as a monitoring technique for release of odurs that indicate spoilage of material or it is ripening level to help take decision on preservation conditions. Samples were placed in cuvettes not tightly closed (just covered) and signal detected through the surrounding atmospher at different times extended to 30 hours. Experiment set up are shown in Fig. 4.19. and results are presented in Fig. 4.20 -4.23.

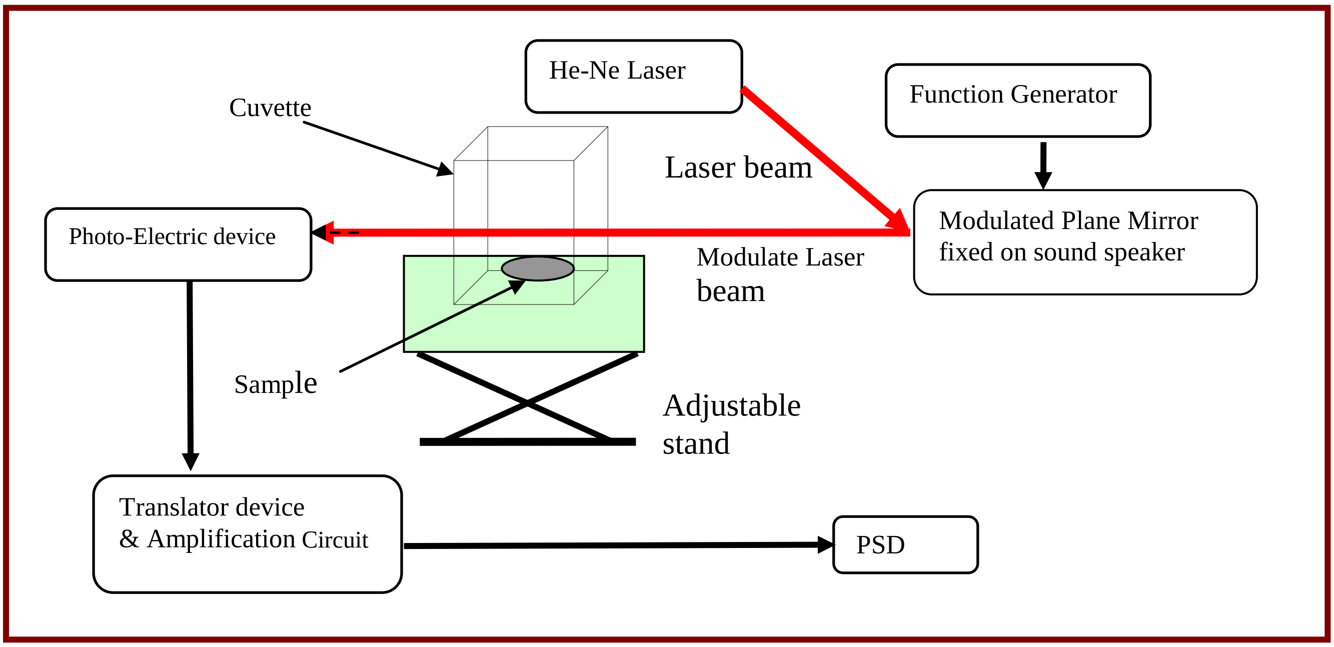


Figure (4.19):- Schemtic shows the experimental arrangement used for vapor release from plant leaves ,fish and meat samples.

Time (Hour)	Fish Detected signal amplitude (arb. units)	Meat Detected signal amplitude (arb. units)	Sage leaves Detected signal amplitude (arb. units)	Mint leaves Detected signal amplitude (arb. units)
0	7.67	6.67	7.38	7.2
0.5	5.59	5.35	4.97	5.24
1	4.99	3.40	4.76	4.25
2	4.14	3.10	4.24	4.5
3	2.56	2.18	3.98	3.48
4	1.81	2.33	2.94	2.09
20	-0.52	-1.55	1.19	0.89
21	-1.02	-1.78	0.07	0.16
22	-1.31	-1.89	-0.08	-0.64
25	-1.8	-2.99	-0.46	-3.05
27	-2.33	-3.50	-1.38	-3.29
29	-5.39	-5.31	-4.3	-4.81
30	-5.57	-6.90	-4.87	-4.99

Table (4.14): The detected signal amplitude of vapor released from one gram sample different materials against time.

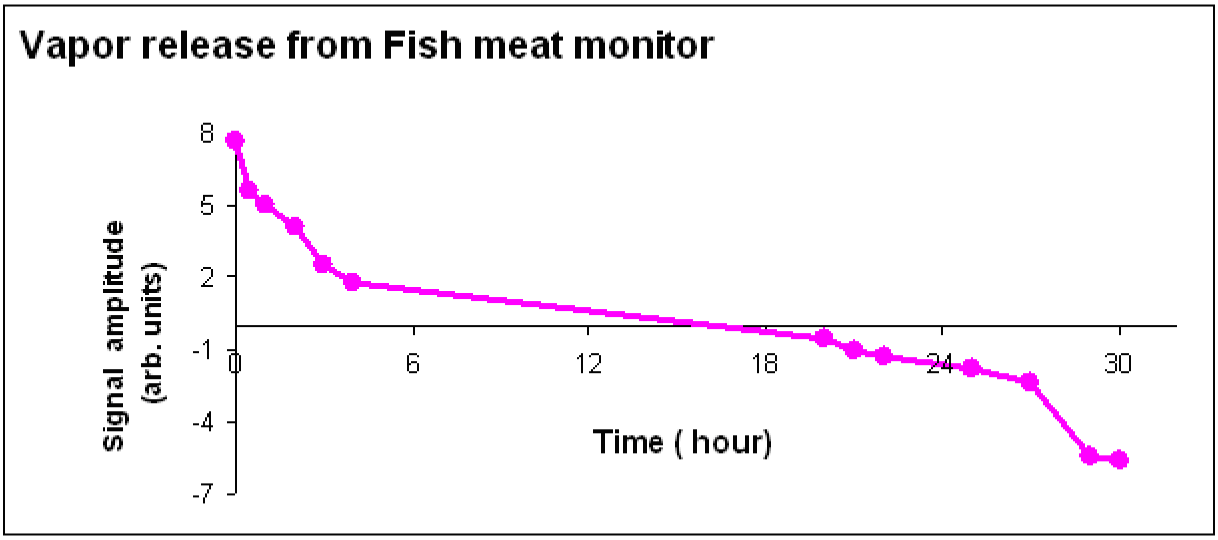


Figure (4.20): Detected signal amplitude through gases released from 1 gm of fish meat sample versus time (Free of measurement region is during night period).

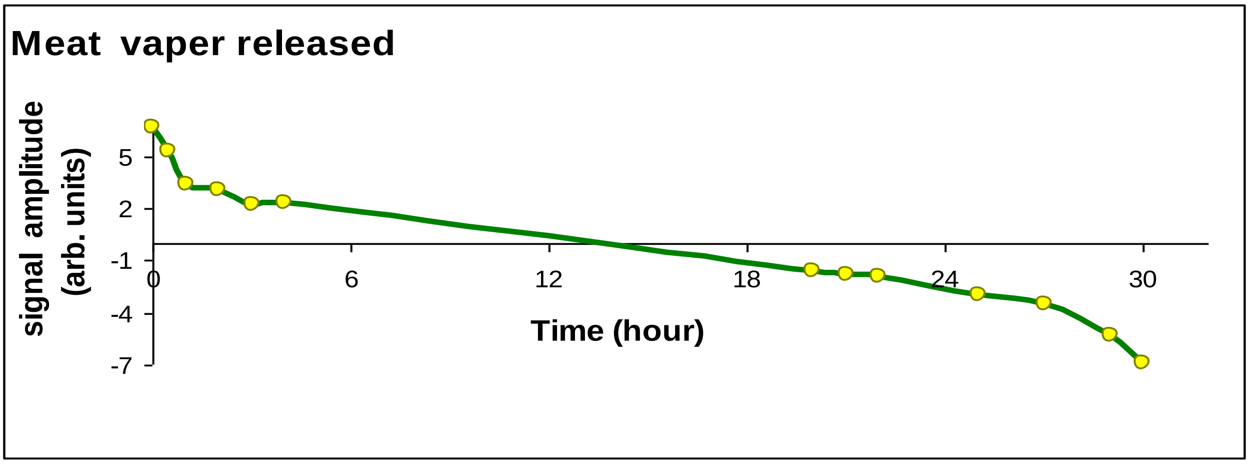


Figure (4.21):- Detected signal amplitude through the gases released from 1 gm of meat sample versus time (Free of measurement region is during night period).

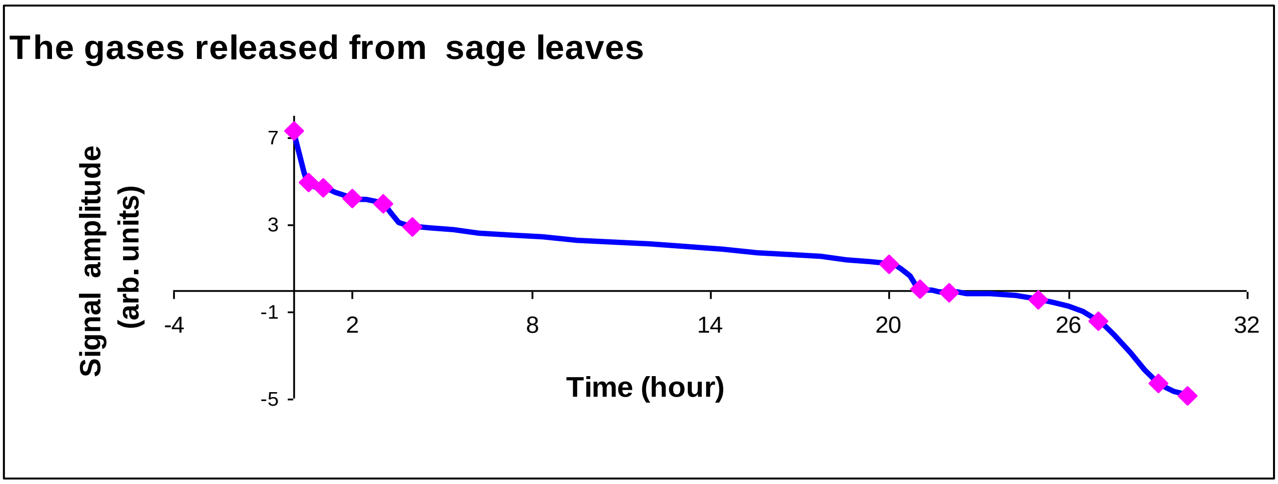


Figure (4.22):- Detected signal amplitude through the vapor released from 1 gm of sage leaves versus time (Free of measurement region is during night period).

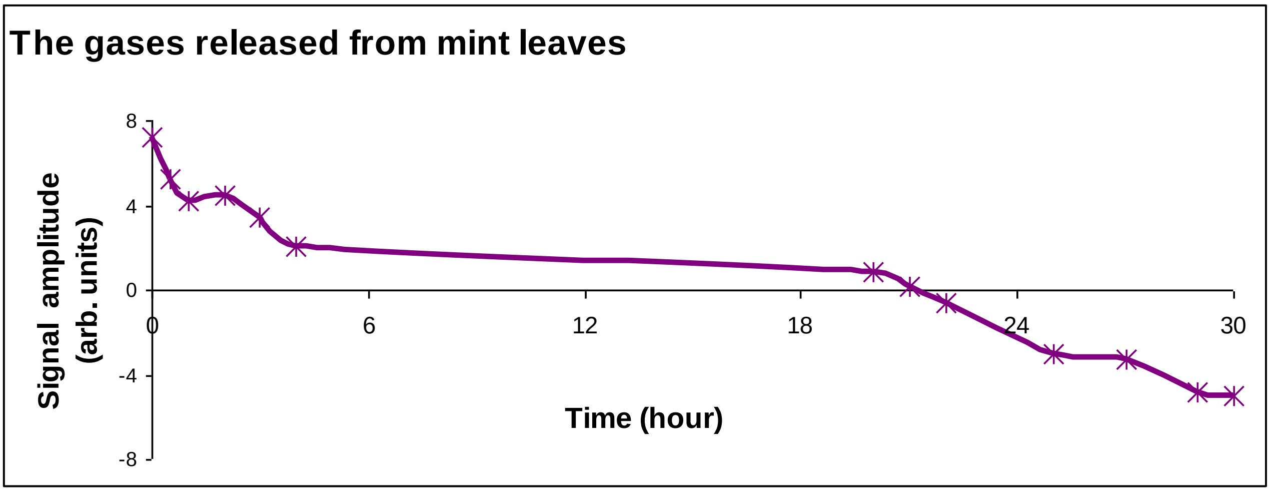


Figure (4.23):- Detected signal amplitude through gases released from 1 gm of mint leaves versus time (Free of measurement region is during night period).

Chapter Five

Discussion and Conclosion and further work

5.1- Disscusion:

In the present work an experimental study was performed to test for : Adulteration of foods, Odor release,water vapor, and smoke release monitor together with other application. These applications can be studied with different types of spectroscopy methods under very stringent conditions especially when light frequency coincidence with one or more of absorption lines of the sample used are required. In this work which to our knowledge the first time was done, efforts were made to alleviate this dependence in a move to enhance applications of He-Ne laser for a variety of applications with ease. In principle detection using this method relied on the bulk absorption or scattering of light energy by the sample under study, although this is expected to be minor compared with light scattering as a result of passing the modulation beam through the medium.

The range of frequencies upon which the system would be sensitive was studied, and it is found over the range of 10 Hz to few KHz, the detector has a good response with the best detecting ability at low frequencies, and the best of all is ~ 17 Hz (see Fig. 4.2). The modulation unit was replaced with a mechanical chopper for comparison , the photodetector and detection unit gave very similar results in both cases over the range of frequencies used. For 1 KHz applied modulation frequenceis, the deviation between frequency detected by instrument and that really applied by chopper and speaker was ± 2 and ± 3 respectively, i.e. the mirror vibration modulation is efficient and comparable to that of chopper (see table 4.1, Fig. 4.4a and Fig. 4.4b). This means that this simple and inexpensive technique, i.e. the modulation using sound speaker is very practical and cut on cost of equipment and practical complication as well.

The quality control is very important in two major aspects, firstly to check that the product meets the standards and secondly to determine its exact shelf life. For orange juice the detected signal amplitude increased, so the absorption or scattering of light energy decreased, becuase the refractive index of orange juice decreased when sample was diluted with drinking water, consequently its concentration was decreasing (see table 4.2 and Fig. 4.5).

Brine exact concentrations are important for preservation of pickled foods and it has its influence on fermentation. Its physical and chemical properties indicate the status of the brined product (Azarnia and Ehsani, 1997). The established test is helpful especially for a factory aiming to keep the same properties of the brine solution; hence the same standerd and qaulity of its product. Tests of brine samples at different stages of pickling allow the determination of the preserved product quality, since it takes into account any changes due to debris of decayed parts of the product and not only salinity changes. The detected signal amplitude through brine solutions decreased when the brine concentrations increased, because the laser beam reflected and refracted from the brine unsoluable parts and so the absorption or scattering of light energy increased (see table 4.7 and Fig. 4.9).

Low sugar concentration levels comparable to that found in human blood were prepared in water and tested. Establishing easy to run measurements of such low sugar values are important in numerous applications. For example the amount of milk and its components (Schoos and Oliver, 1999) and glucose content depends on the type dietary food of the animal (Khalili and Sairanen, 2000). Any ransparent sample is easily checked for suger content and or the general texture. Sugar is hexose which is known in a dextrorotatory polarized light to the right and a levorotatory form will rotate to the left. All hexose taken into animal body are converted into dextorotatory forms (Crawford, 1968). The detected signal amplitude decreaseing for increasing the sugar concentration. (see table 4.7,4.8, Fig. 4.10 and 4.11).

Properties study of materials such as the index of refraction or thichness change can be used to monitor standard fitness of the product. The intention is to establish an easy andquick test of directly monitoring the producation line or at a later stage. The two perameters chosen and tested (see tables 4.13 Fig 4.18). The nature of material depended on the index of refraction that is proptional to the ratio of light speed in the material to the speed of light in vacuum or air. The speed of light transferred the information reverse proportional to the material index of refraction, and depended on the material thickness and then pentration depth.

The ability of the system to discriminate one oil type from another and determination the shelf life of olive oil sample from different production years by studying the signal versus frequency for each type oil (see tables 4.3,4.4 and 4.5, and Figs. 4.6,4.7and Fig. 4.8). The idea is to primarily establish easy adulteration olive oil test. Three oil samples :olive, Blck cumin and vegetable oils were used. The curves obtained have the similar features but distinguishable from each other. This shift depended on the way of oil storage and kind of containers and the storage conditions, like dark place, full bottle, type of bottle and the production oil area.

Smoke, Vapors and bad or good odors detection are very useful tools to monitor processes going on during industry processes or in storage house (Doleman, Lewis, 2001 and Slotnick, Bell, and Panhober, 1997). For example gas release detection of the early stages in a chemical factory especially in hazardous places where workers cannot reach is vital.

Ammonia released from respiratory system can be analyzed for medical diagnostic purposes (Lachish, Rotter, Adler and El-Hanany, 1987). Insects attacking grain (Porter, Hepper, Bouchot and Picard, 1999) in storage house will release gases or odors resulting from microbial activities (Schaller, Bosset and Esher, 1998); when detected in the early satges allows salvage action and product loss avoidance. Some gases when released from vegetables of stored crops making the monitor system extremely important. Few simple tests were carried out to access system ability in detecting gas and bad odors release to control smoke and storage conditions of fish and meat (see tables 4.10, 4.11,and 4.14, Figs 4.14, 4.15, 4.20,4.21,4.22 and 4.23).

This technique is sensitive enough to determine minute changes in index of refraction or transparent material thickness changes and suitable for odor emission monitor.

5.2- Conclusion and further work

The speaker mirror vibration modulation technique had successfully modulated the laser beam intensity as proved in equation 3.4. The variety of experimental result carried out confirms the greater potential in this method which enhanced the use of He-Ne laser in many experiments. Speaker modulated He-Ne laser beam standard calibrated curves could be obtained for each application for simple easy comparison of tested unknown sample. The opportunity is open for many other uses and sensitivity improvements.

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