CHAPTER 3

3.0 Component Used In Optical Coherent Communication

3.1 Introduction

A phase modulated coherent communication system depends on many factors like wavelength of light wave used, its state of polarization, source of light wave, medium of communication, type of light source, type of modulation, type of demodulation, number of channels, rate of data transmission, and type of detector. Most of the components used exhibit wavelength dependencies, as do detectors, polarizers, phase modulator etc. Most of the systems described in this thesis are developed in stages, whereby addition of a new component and its effect on the whole system studied before proceeding to next stage. In order to establish a firm basis of understanding as well as designing a coherent PSK communication system it is important that all individual components have known characteristics. Therefore this chapter briefly describes the optical components and their characteristics.

3.2 Light Source

There are three basic criteria for choosing a proper light source for use in coherent PSK communication systems namely polarization stability with time, line-width, and light wave should correspond to the other devices used in the system, i.e., beam splitter, wave-plate, fiber and detector. All of these components are wavelength dependent, meaning light emitted from the light source must propagate through these devices with minimum loss and that no other effects are imposed on the light. In these experiments laser diodes of wavelength 670nm and 785nm were used, and were characterized beforehand. The output power from these lasers were 5.5mW and 3.5mW respectively. Output from the laser diode is very stable as far as the power and plane of polarization is concerned, the light beam emitted from a laser diode is not symmetrical and it is usually elliptical as shown below.

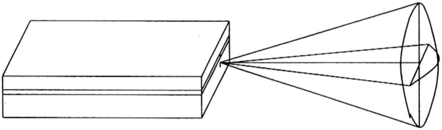

Fig. 3.1 Diode laser with asymmetrical output

If a convex lens is put in front of diode laser, it will cause the light to converge at two different points, It is because of the different divergences along the x-axis and y-axis, an effect that is called astigmatism (refer to appendix B). There is a point between two foci, where the beam profile is circular. A knife-edge technique was used to study the beam profile of the laser diode. A plano-convex lens was used to focus the laser light from the diode, but the plano-convex lens alone does not over come the problem of astigmatism. If only a small portion of the light beam system is used the effect of astigmatism is less pronounced and to this end an adjustable aperture for selecting a small portion of the beam is used. The best-collimated beam is obtained by using a very small aperture after the plano-convex lens.

The laser diode plane of polarization is fairly constant, and does not change with time, even if there is a small back-reflection into the laser diode. Investigation into the variation in plane of the polarization for other light sources, i.e. He-Ne laser was executed since the temporal polarization dynamics was not known. We found the plane of polarization of these sources did not remain constant. In the case of a He-Ne laser, the plane of polarization changes by 90 degrees within 30 minutes. If there is a small back reflection into the He-Ne laser its plane of polarization changes very quickly. This means that such a kind of laser, which can not keep its plane of polarization constant cannot be used in a coherent PSK type of communication system. One of the basic requirements of a coherent PSK communication system is that the plane of polarization of the light wave should remain constant.

There are two reasons why we use diode lasers (670nm and 785nm).

i) Most of our components are optimized for 785nm wavelength and

ii) 670nm-wavelength light is visible, red light. In the case of phase modulation in which the output is in the form of fringes, it enables naked eye inspection before optimizing the system. The basic principles for coherent PSK communication system is independent of wavelength, however it works fine as long as all components are matched with the wavelength of the light source used.

3.3 Variable Aperture

A variable aperture was used for adjusting the power of the light wave and getting the best portion of collimated light. Most detectors can only detect a signal if its power is above a certain threshold level. On the other hand if the power of the ray is above a certain higher limit then the detector will be saturated. As such to avoid both extremes, a variable aperture was used. A small aperture also cut down some variation due to astigmatism in the source output.

3.4 Polarizers

In our design we have used two type of polarizers, sheet polarizers and cube polarizer. A sheet polarizer allows only one plane of light (i.e. electric field) which is along the polarization axis of the polarizer, to pass through. All other polarization planes are absorbed. In the case of a cube type polarizer, two orthogonal planes of polarization are separated. There are three main reasons for using these polarizers, which are

i. Diode lasers have an extinction ratio of 100:1, which means about 1% of diode laser light, is not polarized or orthogonal to the main polarization direction. By using a sheet polarizer this ratio can be increased to around 1000:1.

ii. When a light beam is split into two by a polarizing cube beam splitter, experiments show that the polarized light, which is reflected, contains more than 5% of the orthogonally polarized light. To eliminate or to keep this to minimum we used a sheet polarizer. By reducing this orthogonally polarized portion of the light contrast of the output fringes is improved.

iii. A sheet polarizer is also used for precise intensity control of a polarized light.

3.5 Waveplates

Waveplate or wave shifters include quarter waveplates and half waveplates. Waveplates are made up of birefringent materials, which have two refractive indices, one for ordinary light (O) and the other for extraordinary light (E). A simple waveplate will be a uniaxial crystal cut in such a way that the velocity differences between O and E beam are maximized. As the O and E beams traverse the plate, a phase difference accumulates between the two beams that is proportional to the distance traveled within the plate. At the output face, the O and E beams recombine to form a second mixed polarization, unpolarized beam. Within the waveplate, the crystalline optic axis and its normal are often called the fast or slow axes, depending on whether the uniaxial crystal is positive or negative. Rotating the waveplate slightly about one of these axes can rotate the plane of polarization of the light. It is also possible to adjust the waveplate with respect to slight difference in wavelength. Rotation around the crystalline optic axis also increases effective plate thickness. However, it does not affect velocity difference between O and E rays. Rotation around the other axis also increases the effective plate thickness but reduces the velocity difference between the O and E rays. The latter effect dominates for small rotations, reducing the amount of accumulated path difference between the two rays. If a plate thickness is such that the phase difference is a quarter wavelength, the plate is called a first order quarter waveplate, which was used extensively in our experiments. Similarly if the phase difference at emergence is one half wavelength, the plate is called a first order half wave plate. If the difference at emergence is some multiple of the quarter- or half- wavelength, then the plate is called a multi-order or higher order plate. In the case of these waveplates, names refer to phase difference and not to the thickness. Since O and E ray refractive indices of most materials are wavelength dependent, a path difference which accumulates within the plate of specified thickness is also wavelength dependent. A particular value of path difference can be precisely achieved for normal incidence at only one specified wavelength.

3.5.1 Half Waveplates

Half waveplates allow the polarization plane of a polarized beam to the continuously adjusted without rotating the laser. If a half waveplate is rotated by an angle θ the plane of polarization will rotate by 2θ as shown in the Fig. 3.2.

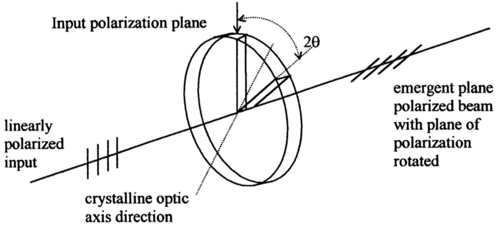

Fig.3.2 Relationship between rotation of waveplate and rotation of plane of polarization.

Since waveplates are wavelength dependent and we have used two different light sources at 670nm and 785nm, we have studied extensively how the waveplates behave at the two different wavelengths.

3.5.2 Quarter Waveplates

Quarter waveplate change a plane polarized light wave into a circularly polarized light wave and vice a versa. In our experiments we have used it extensively for changing the state of polarization and splitting the light wave. We have also investigated the behavior of quarter waveplate at two different wavelengths.

3.6 Beam Splitters

Beam splitters are divided in two types namely polarizing and non-polarizing beam splitter. These are further divided into two subtypes, depending upon their physical shape which can be either in the form of a flat plate or a cube. In our experiments we have used cube beam splitters. Cube beam splitters are easier to mount, are very good for beam superposition and easier to maintain. If there is a polarization maintaining fiber coupler it can easily replace a bulk cube beam splitter. Cube beam splitter consists of matched pairs of right angle prisms cemented together. The hypotenuse of one prism has a partial reflection coating. Usually a black dot on the ground side of prism indicates which prism has the partial reflector on its hypotenuse. The incident beam must enter the prism containing the partial reflector first. Beam splitter, of the non-polarizing dielectric cube type is particularly useful with a randomly polarized light. This type of beam splitters are excellent for combining two orthogonally polarized rays. Since the cube is insensitive to the plane of polarization it can easily split a light ray into two without affecting their state of polarization. In fact this type of cube is one of the most essential component in our experiment. Unavailability of all fiber optical couplers, capable of maintaining polarization plane and independent of plane orientation has restricted the experiment to bulk optics. If we could make such coupler it will greatly improve the performance of coherent PSK communication in general. We will discuss this in the last chapter. Lastly it is important to use antireflection-coated cubes because back reflection adds noise to the system. Even then it is recommended to use isolator wherever it is necessary.

These types beam splitters are very useful for separating two orthogonal plane polarized rays. It can also be used to combine two orthogonal plane polarized lights. When a beam of ordinary light is incident at an angle on a transmission dielectric such as glass, the emerging refracted ray is partially linearly polarized. For a single surface (with n = 1.50) at Brewster's angle, 100% of the light whose electric field vector oscillates parallel to the plane of incidence is transmitted. On the other hand only 85% of the polarized light perpendicular to the surface is transmitted and the other 15% is reflected. If a number of these plates oriented at their Brewster's angle are stacked parallel electric field vibrations perpendicular to the plane of incidence, will be reflected at each surface and all those parallel to the surfaces will be refracted. By including a large number of these plates within the stack (greater than 25), a high degree of linear polarization may be achieved however this type of polarizing beam splitter is not very efficient for coherent PSK communication because it introduces complicated phase shifts in the reflected light. The difference between the ordinary and extraordinary ray may be used to create birefringent crystal polarization devices. The difference in refractive index is used as a primary method to separate the rays and eliminate one of the polarization planes as is seen with a Glan polarizer. This polarizing beam splitter, does not add complicated phase differences as in the case of a reflection type polarizing beam splitter.

3.7 Mirror

In the ensuing experiments protected metallic coated plane mirror is used. The total mass of the mirror is important parameter in the experiment because a path length difference created by moving mirror back and forth. At high frequencies the movement, is affected by inertia of the mirror. It can be seen in all the output waveform in the experiments.

3.8 Piezoelectric

When some crystalline material exhibits electro-strition are compressed, they produce a voltage proportional to the pressure. This is called the piezoelectric effect. Similarly when the electric field is applied to such a material, it changes its shape. Several natural materials exhibit piezoelectric properties, but most devices now use polycrystalline ceramics, such as lead zirconate titnate (PZT). With traditional materials and design, linear displacements of up to about 100 nm are obtained with application of high voltage. Although voltage is needed for the piezoelectric effect, power consumption is low, and almost no energy is consumed in maintaining a fixed position with a fixed load since the impedances are very high so no current sinks. Piezoelectrics can respond to changing input voltage with micro-second time constants, and position resolution is limited only by power noise. One of the reason a piezoelectric was used in this work as an optical path length modulator because a very small calculated displacement can be created by applying a proper voltage which is discussed in detail in section 5.3.

3.9 Power / Energy Meter

The Ophir Nova power / energy meter is used for monitoring the light wave power. A micro processor-based Laser Power / energy Meter providing a broad range of measurements, displays, and data handling operations and operates with thermopile, pyroelectric, or photodiode heads, and uses a smart connector technology. Though this meter can operate with different types of detectors but in the experiments described it is used in conjunction with a photodiode head, PD300. The PD300 head has a unique dual detector head in which there are two identical detectors connected back to back. When a uniform signal, such as room light background falls on the detector head, the signals from the two detectors cancel. On the other hand, when a laser beam falls on the head, it illuminates only the first detector and therefore is detected. The PD300 subtracts most of the background while detecting the desired signal. The subtraction is not perfect but usually 98% of the background signal is eliminated. The PD300 photo diode head together with the Ophir Nova meter displays a large dynamic range from nano-watts to hundreds of milli-watts. PD300 is constructed with a built in filter so the basic head can measure to 30mW without saturation. When the additional filter is installed, the maximum power is on the order of 300mW. The PD300 saturates when the output current exceeds 1mA so the exact maximum power depends on the sensitivity of the detector at the wavelength used. The actual maximum power as a function of wavelength is given below which is provided by the manufacturer.

Maximum Measurable Laser Power As A Function Of Wavelength

WAVELENGTH	MAXIMUM POWER	
	FILTER OUT	FILTER IN
<488nm	30mW	300mW
633nm	20mW	300mW
670nm	13mW	200mW
790nm	10mW	100mW
904nm	10mW	150mW
1064nm	25mW	250mW

The PD300 has a built in wavelength correction curve for measurements either with the removable filter installed (filter in) or removed (filter out). These curves are stored in its EEPROM. The Nova also has the option of graphing the laser power vs. time, or successive energy points as long as the Nova has not been turned off. The Nova will record data until the screen is full, or "reset" or "exit" is pressed. If the laser power is fluctuating, the Nova can also display the average power readings with averaging period varying from 1/3s to 1 hour.

Photodiode detectors are inherently very linear but also have a large variation in sensitivity with wavelength. In addition, the Opher model PD300, which is used in the experiments, is equipped with both a built in filter and a removable filter to allow measurement of higher powers without detector saturation. These filters, however, also have a transmission, which depends on wavelength. Therefore, the PD300 Nova has a built in calibration adjustment for all the wavelengths. When the user selects certain wavelength on Nova, the correction factor for all that wavelength is automatically applied. Since the instruments are calibrated to NIST standards, the accuracy is generally

±2% at the wavelength at which calibration has been performed. The maximum error in measurement will be less than the sum of the calibration accuracy, linearity, and inaccuracy due to errors in the wavelength curve and variations in gain with temperature. This linearity of the photodiode detector is extremely high and error due to this factor can be ignored. The maximum error due to the above factors is provided by the manufacturer and is given below.

Maximum Error As A Function Of Wavelength And Filter

WAVELENGTH	ERROR	
	Filter out	Filter in
350-950nm	±5%	±8%
950-1100nm	±7%	±10%

3.10 Oscilloscope

In our experiments we have used HP 54510A Digitizing Oscilloscope. This is a general-purpose repetitive and real-time oscilloscope, fully programmable and transportable. It has two input channels and an external trigger input. Full HP-IB programmability is incorporated for use in a broad range of HP-IB applications, from high-speed to device characterization in research and development environments. The HP 54510A also features powerful triggering, easy waveform storage, automatic measurements, and instant hardcopy output. HP 54510A is used with a HP-IB compatible printer or plotter. It has an amplifier, bandwidth of 250MHz, which gives an indication of the usable upper-limit frequency as a single-shot event.

3.11 Signal Generator

Different type of signal generator is needed for testing a multi-channel communication system. First, each channel has to be tested separately and then all channels need to be tested simultaneously when all inputs are activated. The second part is more important because it will test the level of interference between the different channels if any. There were four basic criteria set for the design of signal generator.

i. Signal generator should produce at least two different types of signals, which should be different in shape.

ii. The two signals should have a constant phase difference. It will help to locate the position of optical interference fringes, if any.

iii. The frequency should be such that piezo-electric system should be able to operate (piezo-electric can not operate at very high frequencies).

iv. Signal amplitude should be variable.

To satisfy above conditions, a simple TTL based, 1 kHz signal generator was developed as is shown below.

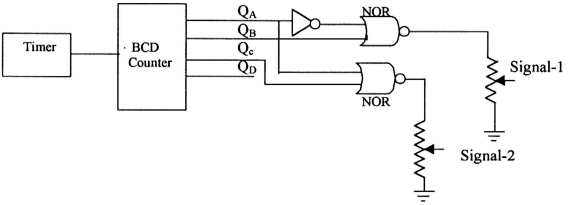

Fig. 3.2 Block diagram of electronics for producing two different types of signals.

Binary Logic for signal generator

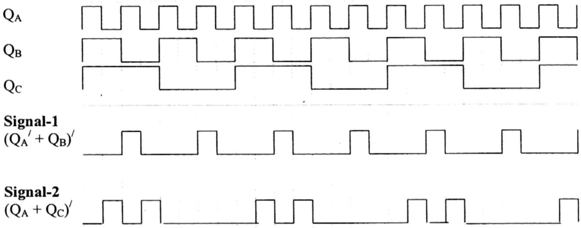

Fig. 3.3 Timing diagrams for signal-1 and signal-2.

The signal generator designed satisfies all the required conditions for testing the communication system.

i. There are two different signals, which can be easily recognized.

ii. There is a permanent phase correlation between the two signals, which is independent of frequency and amplitude.

iii. Changing the variable resistors in the timer circuit (not shown in the diagram) changes signal frequency.

iv. Changing the variable resistors labeled as signal-1 and signal-2 change the amplitude.

When these signals were applied to the piezo-electric modulator it changes its shape due to large time constant. It is because of high capacitance associated with the piezo-electric modulator. These signals are used for testing all the PSK communication designs. After connecting to the piezo-electric modulator the change in signal shape from a square wave to that with different exponential rising and falling edges because of change nature of circuit is given below.

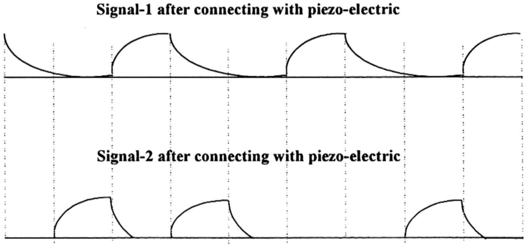

Fig. 3.4 Timing diagrams of output signal-1 and output signal-2 after connection to modulator.

3.12 Receiver

In most coherent phase modulation techniques when the signal lightwave reaches the surface of a detector, it is mixed with the reference light wave (or lightwave from a local oscillator). To decode a signal from the mixed light wave we have developed a technique whereby first the light beam is expanded with a plano-convex lens and then this expanded beam which has bright and dark fringes due to the interaction between the reference light-wave and signal light wave is projected over a photodiode. This interaction pattern is only possible if the path lengths between signal-light-wave and reference-light-wave are less than coherent length of the laser source.

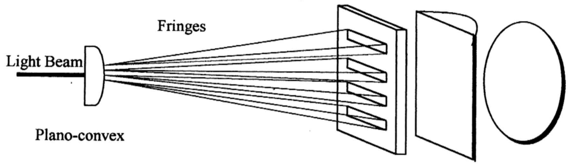

Fig. 3.5 Signal decoding arrangement

If the signal light is removed, there will be no interference pattern and any light wave after the lens will be almost uniform. But when signal light is turned on the interference pattern will reappear. The fringes produced are such that there are bright and dark bands but the dark bands are not totally dark. This is so, because the intensities of two light beams, signal and reference light wave, are not the same. Usually the intensity of reference light wave is many times stronger than the intensity of the signal light wave. The reason for this has been discussed in detail in the Chapter 2, section 2.1.2. The bright and dark fringes start moving up and down or left and right with respect to the optical table plane, depending on the apparatus setting, when a signal is applied to the piezo-electric modulator.

By inserting the multiple-slits, any variation in the intensity on the detector surface is increased many fold and this makes it is easier for the detector to detect the variation. In the absence of the multiple-slits it is difficult to detect the variation in the intensity. In other words the detector will not detect any intensity variation specially if the interference fringes are closely spaced.

In our experiments we have used free space bulk optics in which we get parallel fringes so parallel multiple slits are used. But if we used optical fiber instead of free space fringes will be circular and then circular multiple slits should be used.

Distance and orientation of the multiple-slit screen must be adjusted such that only one bright line passes through one slit. In other words the spacing between the fringes and the spacing between the slits in the slit screen must be equal, as shown in Fig. 3.6. Focal length of plano-convex lens is 10 cm. The distance between lens and screen varies for experiment to experiment which also dependent on angel between single carrying light wave and reference light wave.

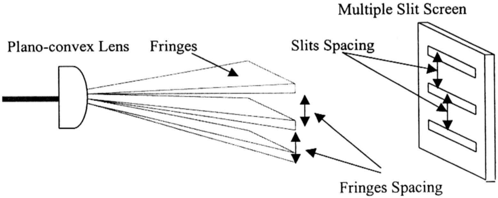

Fig. 3.6 Arrangement of intensifying signal output.

Usually the slit spacing is fixed but fringe spacing changes with distance from the plano-convex lens, so by changing the distance between the lens and the multiple slit screen these two spacings can be matched. Slits must be parallel to the fringes for maximum contrast on the other side of the screen. A cylindrical lens is used to converge the bright and dark lines on to the photodiode. When the fringes oscillate maximum intensity change occurs on the surface of the photodiode, which is easily detected. Using this technique we are able to decode any signal.