CHAPTER 6

6.0 COHERENT PSK COMMUNICATION SYSTEM DESIGN

6.1 Introduction

In the course of this work, five different coherent PSK communication systems were designed. Four of which are based on fixed coherence length while the last one depends on variation of coherence length. In all cases the reference lightwave is taken from the same source which reduces the effect of phase and frequency jitter in the system. The system is developed in stages, first the coherent PSK communication function of each component is explained in detail while in their systems only unique parts of the system are explained in detail. These systems are

i. All optical two channels PSK communication, using a single light source.

ii. All optical single channel, two-way PSK communications using a single light source.

iii. All optical single channel, two-way PSK communication, using a single light source and without a time delay unit.

iv. All optical two-way PSK communication, using a single light source.

v. Coherence length dependent multi-channel PSK communication system, using a single light source.

6.2 All Optical Two-Channel PSK Communication, Using A Single Light Source

The present design in consideration is a dual channel, dual-polarization; phase shift keying, communication system utilizing a single light source. This system is divided into two main parts, transmitter and receiver. There are two different ways of designing a transmitter. One is based on the Mach Zehnder technique and the second uses a Michelson technique.

6.2.1 Transmitter Design Using A Mach Zehnder Technique

In this technique, a diode laser is arranged in such a way that light beam from laser is parallel to the reference plane, in this case, surface of optical table as shown in Fig. 6.1. Since the diode laser light may not have only one plane of polarization (extinction ratio between p-plane and s-plane is about 100:1). The laser beam passes through a sheet plane polarizer, which absorbs 1% light wave which is unpolarized in that plane. A variable aperture is placed in front of sheet-plan-polarizer, which is used to control the intensity of the lightwave. An isolator is used in front of the variable-aperture, which protects the diode laser from back-reflected light. The light beam is split into two parts by non-polarizing cube beam splitter (NPBS-1), one portion of light is reflected toward mirror-1 and the other part of light goes straight. Two half-waveplates are placed in the path of these two light-waves. Half-waveplate-1 is placed in between NPBS-1 and mirror-1 which rotates the light beam by 45°. This light wave which is then reflected by the mirror-1, is not modulated and is called the reference light wave. The other part of

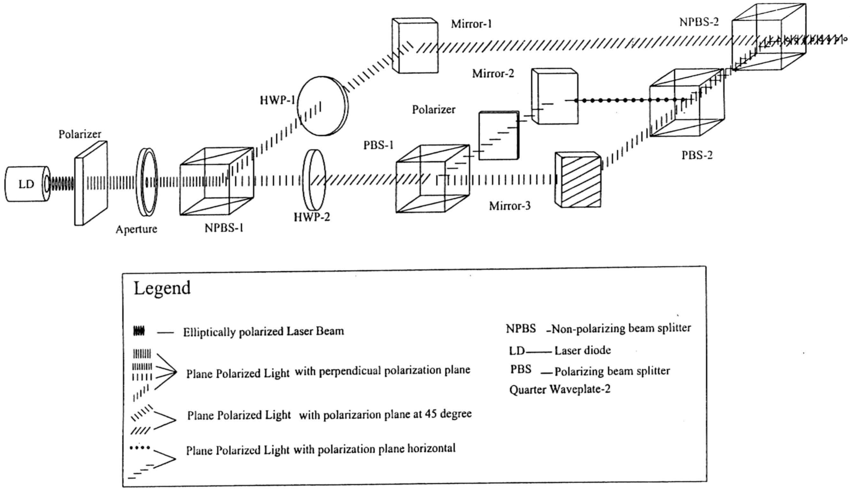


Fig. 6.1 Transmitter portion of all optical PSK communication, using a single light source and the Mach Zehnder Technique.

the light-wave, which passes straight through NPBS1, is also rotated by the half-waveplate-2 by an angle of 45°. This 45° inclined plane polarized Light wave is again split into two parts by polarizing beam splitter (PBS-1). This beam splitter not only splits the light into two light waves but also splits their polarization vector into two components with their planes of polarization orthogonal to each other.

Half-waveplate-2 is also used to control the relative intensities of these two light waves. One part of the lightwave which goes straight has the plane of polarization perpendicular to the table while the other part of light wave which is reflected at 90 degree has a plane of polarization parallel to the table. Both of these orthogonally polarized light waves are reflected by mirror-3 and mirror-2 respectively. These mirrors are attached to piezo-electric elements, which provide translation motion back and forth with the application of proper electric field to the elements. These piezo-electrics, with the help of mirror-2 and mirror-3, are used for encoding the signals. A sheet-plane-polarizer is placed between NPBS-1 and mirror-3 which This helps to remove any vertically polarized light contained, which is reflected toward mirror-2 by PBS-1. Both orthogonal signal carrying light waves, after being reflected by the mirror-2 and mirror-3 are combined by a polarizing beam splitter-2 (PBS-2). Since a plane polarized light which is perpendicular to the polarized plane passes straight through PBS-2 while any horizontally polarized light is reflected. Both rays will travel along the same direction. These two signal carrying rays will be combined with the reference by non-polarizing beam splitter-2 (NPBS-2). NPBS-2 will split all incident rays into two without affecting their plane of polarization. Light-waves will emerge from both side of NPBS-2 and will have three kinds of plane polarized light. A perpendicularly plane polarized light-wave which carries signal encoded by mirror-3, a horizontal plane polarized light wave which carries signal encoded by mirror-2, and the reference light which is reflected by mirror-1 and its plane of polarization is 45° to horizontal. Now all these three rays can travel through a polarization-maintaining fiber or free space. In this experiment free space is used. On the receiving end, polarizing beam splitter-3 (PBS-3) is used to separates two orthogonal signals carrying light waves as shown in Fig. 6.2. PBS-3 not only separated two orthogonal light waves but also splits the reference light into two orthogonal light-waves since it is 45^0 polarized. Now on each emerging side there are two parallel light waves with same polarization. One is phase modulated by the piezo-electric mirrors while the other is the un-modulated light wave called reference light wave. These orthogonal light waves interact with their respective signal carrying light waves and create an interference pattern. Signals can easily be decoded from time varying interference patterns as explained in chapter 5.

6.2.2 Receiver

A receiver is designed by combining a polarizing beam splitter cube, multiple-slit screen, cylindrical lenses and detectors. Light emerging on each side of the polarizing beam splitter-3 is expanded by a plano-convex lens and on the other side of the lens, fringes can be easily observed. These fringes then pass through multiple slits. When a mirror vibrates along the direction of the light it changes the path-length, which in turn encodes a signal on the light-beam. When this signal carrying light wave interacts with the reference, which is also derived from the same source, it produces an interference pattern with bright and dark fringes. These fringes vibrate with same frequency as the vibration of the mirror. The width of the fringes and of the multiple slits can be adjusted in such a way that only bright fringes pass through the slits while the dark fringes fall on the opaque part of the slits. In this way maximum contrast is produced on the other side of the multiple slit. Fringes after the multiple slits are focused by a cylindrical lens, as shown in Fig. 6.2.

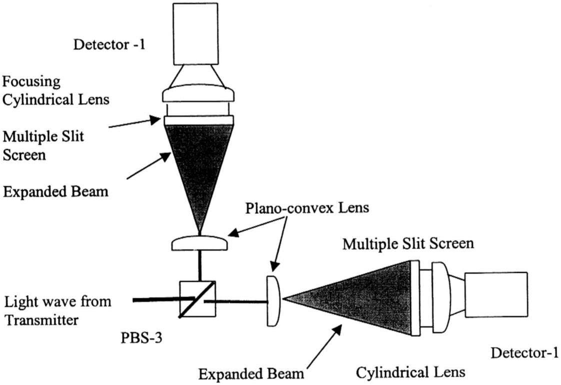


Fig 6.2 Receiver part of the system highlighting various components of a receiver.

On the other side of the cylindrical lens a Silicon PIN detector from Newport part number 818-SL, is placed which detects the signal. Signal encoded by the mirror-3 is detected by detector-1 and signal encoded by mirror-2 is detected by detector-2. Since these two signals are carried by two orthogonal polarized light waves they do not interfere with each other. In the above design Mach Zehnder Interferometer technique is used.

6.2.3 Receiver Design Using Michelson Interferometer Technique

A similar system can be designed using a Michelson Interferometer. Schematic representation of the transmitter design based on Michelson technique is given Fig.6.3.

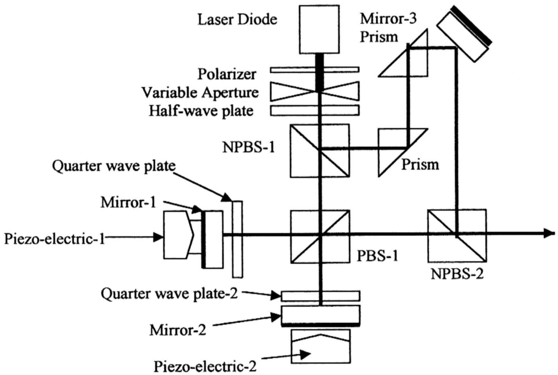


Figure 6.3 Transmitter part of the system designed by using Michelsons technique.

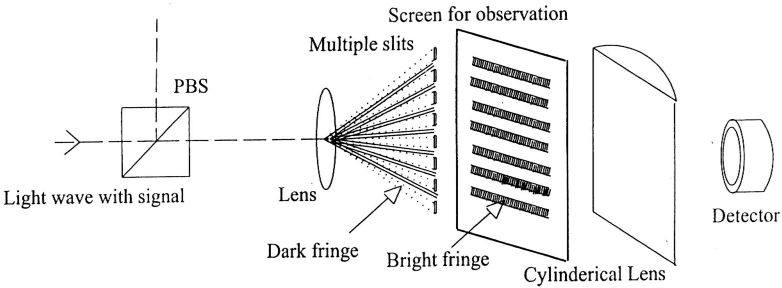


Fig. 6.5 Component arrangement for phase modulation decoder.

In the above diagram a diode laser is arranged in such a way that the laser beam is horizontal to the optical table and its plane of polarization is vertical. A polarizer is placed in front of the laser diode to eliminate any unpolarized light wave. A variable aperture is also used for controlling the intensity of the light wave. In front of the variable aperture a half-wave plate is placed which is used for rotating the plane of polarization. This wave plate is adjusted in such a way that plane of polarization is incident at 45^0 to the polarizing axis of the polarizing plate. This polarized light wave is split into two by a non-polarizing beam splitter-1 (NPBS-1) without affecting the plane of polarization. One portion of the light wave is reflected while the other part passes through. The light wave which is reflected back from the mirror-3, becomes the reference light wave. The part of light which passes through the non-polarizing beam splitter (NPBS-1) is again split into two orthogonal polarized light waves by polarizing beam splitter-1 (PBS-1). Light waves which pass straight through PBS-1 have a plane of polarization perpendicular to table top while the portion of the lightwave which is reflected at 90^0 by PBS-1 has a plane of polarization which is horizontal. When this parallel-polarized lightwave passes through quarter waveplate-1 it becomes circularly polarized is reflected back by plane mirror-1. This mirror is attached to piezo-electric, which can vibrate mirror-1 in the direction of the lightwave and modulates the path-length, which in turn generates a phase modulation. When this phase modulated circularly polarized light wave again passes through quarter waveplate it changes again into a plane polarized light wave but this time its plane of polarization of light wave is perpendicular to the table instead of parallel. This light wave simply passes through PBS-1 towards non-polarizing beam splitter-2 (NPBS-2). Similarly a portion of the lightwave coming from laser the diode which passes straight through PBS-1 goes through the same process but the polarization plans of this lightwave is horizontal. Therefore this light wave is reflected by PBS-1. Now both orthogonal lightwaves encoded with signals are combined with the reference light wave by (NPBS-2). The reference light, which emerges from NPBS-1, is reflected twice by right angle prisms and a plane mirror-3 and finally reaches to NPBS-2 where it is combined with the other two orthogonal signal carrying light waves. Light emerging from NPBS-2.

Therefore light-wave has three planes polarized light waves. Two light waves have their plane of polarization perpendicular to each other while the third light wave has its plane of polarization at 45^0 to the horizontal.

The receiving part is similar to that shown in Fig. 6.2 where a signal encoded by mirror-1 is detected by detector-1 and a signal encoded by mirror-2 is detected by detector-2. Two right angle prisms are used to compensate additional path length differences created by mirror-1 and mirror-2. Phase modulation, utilizing the piezo-electric modulator, was used to test the design.

Additionally $LiNbO_3$ crystals can be used for phase modulation and there should be placed between PBS-1 and the quarter wave-plates. Since a $LiNbO_3$ crystal is polarization dependent it must be placed according to the polarization plane of the lightwave which is to be modulated. The light wave passes through the $LiNbO_3$ crystal twice but only one plane of polarization will be modulated, which is along the crystal axis while the other plane of polarized light will remain unaffected.

6.2.4 Results

To test the optical circuits signals are modulated using simple TTL devices and from these two different types are generated. The circuit diagram for these signals is shown in Fig. 6.4. These signals are used as input signals for the different channels. In Figure 6.1 mirror-3 is fitted to the piezo-electric element which is used as input for channel-1. The output of this signal is detected by detector-1 in Fig. 6.2. Similarly, mirror-2 is also fitted to the piezo-electric element which is used as input for channel-2 and output of channel-2 is detected by the detector-2 in Fig. 6.2.

Signal generator circuit for testing the communication design is given in the Fig. 6.4.

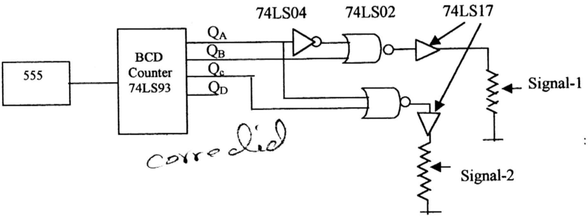


Fig. 6.4 Schematic of electronics generating two distinct drive signals.

First the input signal for channel-1 is turned on while keeping the signal for channel-2 off and output of channel-1 is detected. Input and output of channel-1 are recorded and plotted simultaneously as shown in the Fig. 6.6 Then the signal for channel-2 was turned on while signal is turned for channel-1 is off and input and output from channel-2 are recorded and plotted simultaneously as shown in Fig. 6.7. Lastly both inputs are turned on simultaneously and their inputs and outputs are recorded and plotted simultaneously as show in Figure 6.8 and Figure 6.9 respectively.

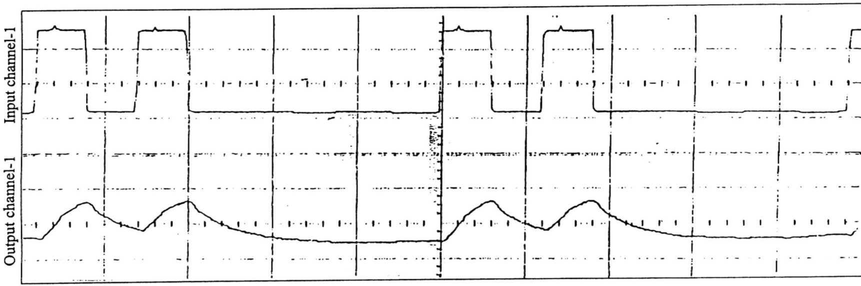
A one way two-channel phase shift communication system was also designed by using a Michelson Interferometer as shown in Fig. 6.3. In this circuit mirror-1 is used as input for channel-1 and its corresponding output is from detector-1, and channel-1 input and output signal graphs are plotted which is shown in Fig. 6.10. Similarly mirror-2 is used as input for channel-2 with its corresponding output from detector-2 and using channel-2 input and output signal graphs are plotted in Fig. 6.11.

Lastly both signals are applied to channel-1 and channle-2 and their inputs and outputs are plotted simultaneously which are shown in Figure 6.12 and Figure 6.13 respectively.

Results show that the output signal is similar to the input signal. It is also observed that both channels are independent of each other. In close scrutiny, two kinds of distortions are found. First is the shape of the wave where the input signal is square wave and the output signal looks like a sine wave. This is due to the capacitance of the piezo-electric element. Because of the large area of the crystal, each piezo-electric element have a large capacitance. Input signals are taken before the buffer (74LS17) where it is square wave as shown in Fig. 6.6, Fig. 6.7 and Fig. 6.9. Input signals after the buffer (74LS17), then the output signals and input signals are similar as shown in Fig. 6.10 and Fig. 6.11. Secondly there is some time delay between the input and output signals. This time delay is less than 10^{-3} second and is attributed to inertia of the mirrors attached to the piezo-electric elements.

In the second set-up which is shown in Fig. 6.3 a Michelson method is used and inputs are detected after the piezo-electric driver or buffer circuit 74LS17. In Figure 6.10 and Figure 6.11 it is observed that the inputs and outputs are closely related except for the sharp edges of the wave which is due to inertia of the mirrors attached to the piezo-electric element. It is clear from Fig. 6.13 that the output is an inverted input. This is due to miss-positioning the slit at the detector as shown in Fig. 6.5. If the slit, which lets through only one fringe, pass through, is positioned at a bright fringe when no signal is applied then on applying voltage this fringe moves to a new position and creates a dark fringe at the slit's opening and the detector will detect a low intensity. So an inverted output as shown in Fig. 6.13 is obtained. All these results confirm that a one way two-channel phase shift communication is possible.

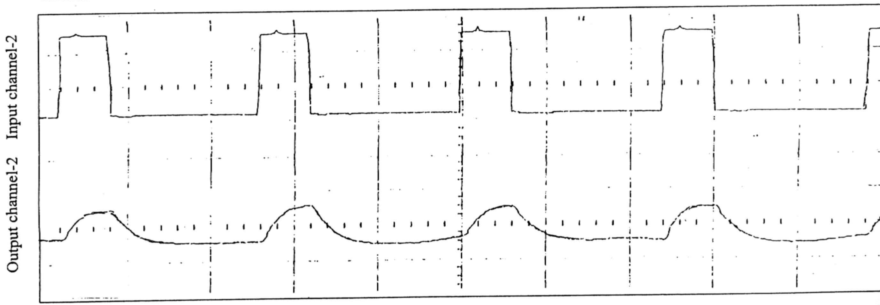
-5.00000nm	Main: 1.00 ms/div	CENTER 0.00000 s	REPETITIVE	5-00000 ms
-5.00000nm	1.00 ms/div	0.00000 s	AVERAGE 8	5-00000 ms



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	2.00 V/div	1.75000 V	1:1	dc	1M ohm
Channel 2	20.0 mV/div	277.600 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive Edge of Channel 1
Trigger Level (s)
Channel 1 = 1.76500 V (noise reject OFF)
Holdoff = 40.000 ns

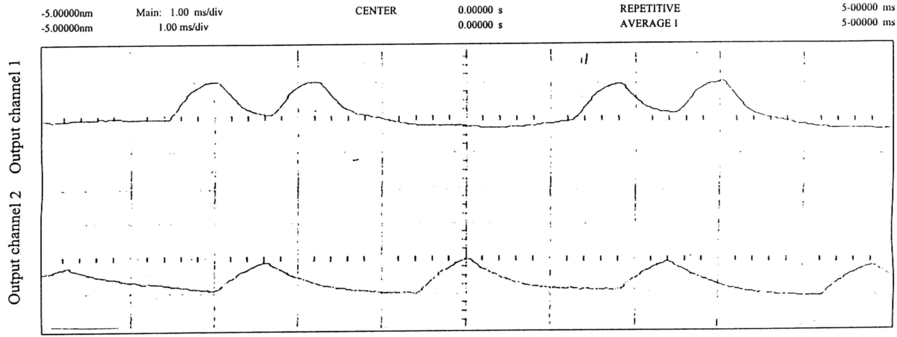
Fir. 6.6 Input output graph of channel-1 when channel-2 is not activated. Input signal is taken before piezo-electric driver and output is detected by the detector-1 as shown in Fig. 6.2



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	2.00 V/div	1.75000 V	1: 1	dc	1M ohm
Channel 2	20.0 mV/div	277.600 mV	1: 1	dc	1M ohm

Trigger Mode: Edge
On the Positive Edge of Channel 1
Trigger Level (s)
Channel 1 = 1.76500 V (noise reject OFF)
Holdoff = 40.000 ns

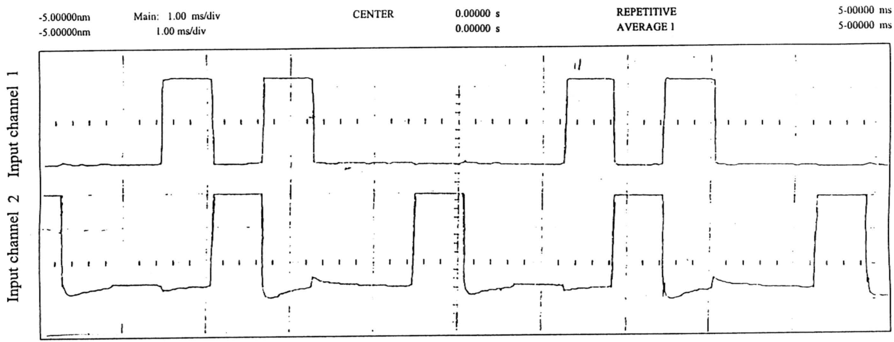
Fig. 6.7 Input output of channel-2, when channel-1 is not used. Input signal is detected before piezo-electric driver. Output singal is detected by the detector-2 which is shown in Fig. 6.2.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	20.0 mV/div	265.000 mV	1:1	dc	1M ohm
Channel 2	20.0 mV/div	260.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive Edge of External
Trigger Level (s)
External = 312.500 mV (noise rejuection OFF)
Holdoff = 40.000 ns

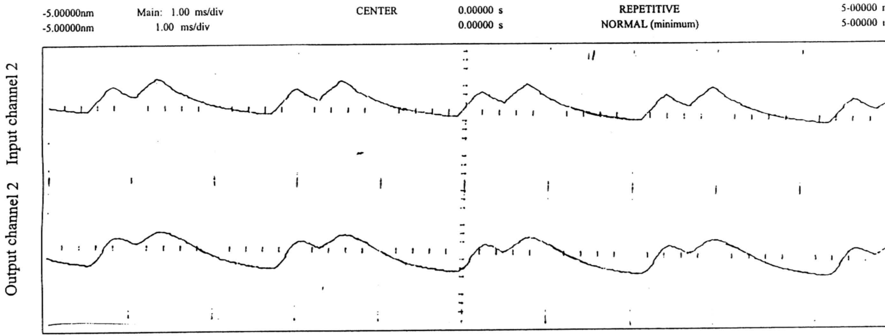
Fig. 6.8 Both outputs of channel-1 and channel-2 when both inputs are activated simultaneously.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	2.00 mV/div	2.50000 V	1: 1	dc	1M ohm
Channel 2	20.0 mV/div	260.000 mV	1: 1	dc	1M ohm

Trigger Mode: Edge
On the Positive Edge of External
Trigger Level (s)
External = 0.00000 V (noise reject OFF)
Holdoff = 40.000 ns

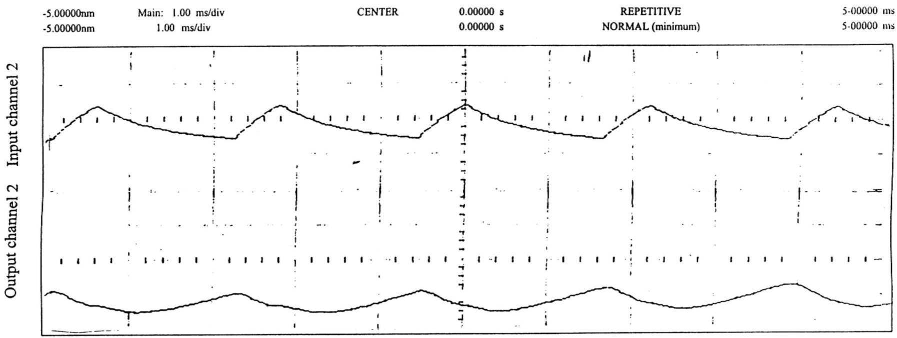
Fig. 6.9 Two simultaneous inputs of channel-1 and channel-2 which are recored before the piezo-electric drivers.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	2.00 mV/div	1.43750 V	1: 1	dc	1M ohm
Channel 2	4.00 mV/div	298.000 mV	1: 1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 1.93750 V (noise reject OFF)
Holdoff = 40.000 ns

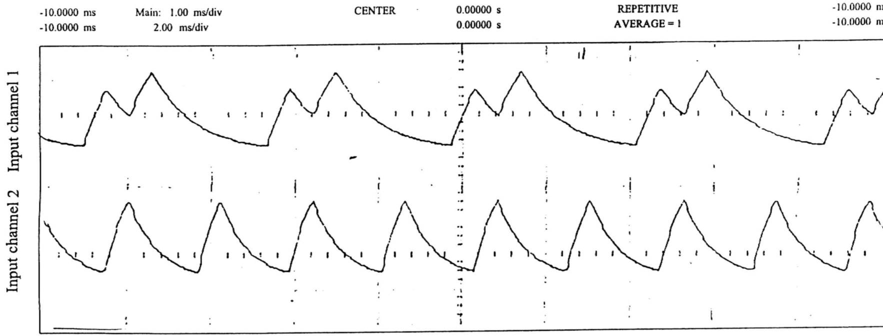
Fig. 6.10 Input output signal when variation in the path difference is one wavelength.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	2.00 mV/div	1.43750 V	1:1	dc	1M ohm
Channel 2	20.0 mV/div	290.625 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 1.93750 V (noise reject OFF)
Holdoff = 40.000 ns

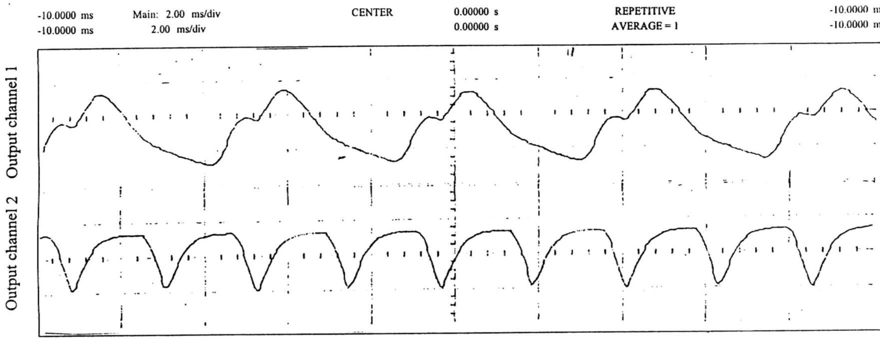
Fig. 6.11 Input output graph of channel-2 when channel-1 is not activated. Input signal is recorded after the peizo-electric driver.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	1.00 V/div	1.12500 V	1:1	dc	1M ohm
Channel 2	1.00 V/div	800.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 765.000 mV (noise reject OFF)
Holdoff = 40.000 ns

Fig. 6.12 Two simultaneous inputs of channel-1 and channel-2, recorded just after the piezo-electric dirver.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	10.0 mV/div	252.600 V	1:1	dc	1M ohm
Channel 2	20.0 mV/div	339.400 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 254.100 mV (noise reject OFF)
Holdoff = 40.000 ns

Fig. 6.13 Two simultaneous outputs of channel 1 and channel 2

6.3 All Optical Single Channel, Two-Ways PSK Communication, By Using Single Light Source

In this system polarized light source is divided into two parts, one of which is used to carry signal and second one is used as a reference. When these two light-waves reached receiver side, reference light-wave is divided into two components. One of which is along the signal while other one is perpendicular to signal. Signal is decoded by interaction of light-wave signal and of reference light-wave. Other part of the reference light-wave can be encoded and reflected back towards the source side. At the source point, the coming back signal can be decoded by interacting it with the portion of the reference light-wave. In this way two-way communication system is achieved. There are two separate designs for this type of communication.

First system which is designed here use Mach Zehnder method in which light beam is divided by a beam splitter and then recombined by another beam splitter. Schematic diagram is given in Fig. 6.14.

Plane polarized light incident on the non-polarized beam splitter (NPBS-1). Light-wave is divided into two parts. A variable aperture is placed between laser diode and NPBS-1 to control the intensity of light beam. Signal is encoded by $LiNbO_3$-1 on one part of light-wave. A half wave-plate-1 is placed between $LiNbO_3$-1 and NPBS-1. This half wave-plate is used to align plane of polarization vector to plane of polarized beam-splitter (PBS1) such that all light-wave should be reflected by PBS-1 to semi-transparent glass plate. A polarizer is also placed between PBS1 and $LiNbO_3$-1. This polarizer is used to block light-wave coming in opposite direction.

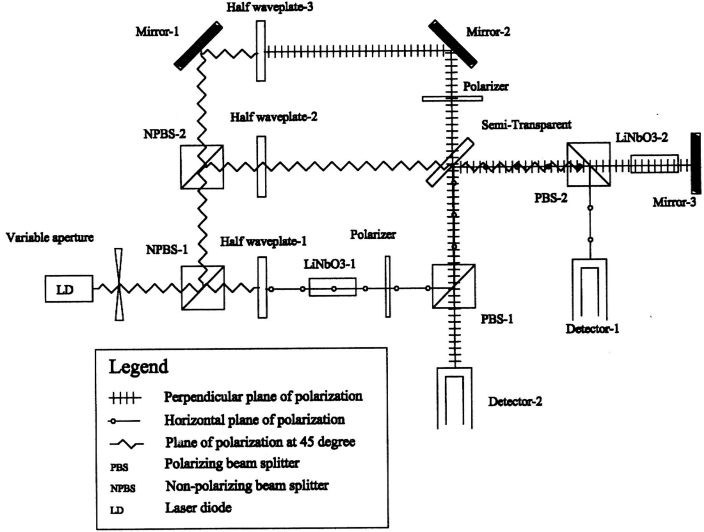


Fig. 6.14 Component arrangement for single channel, two-way communication system using Mach Zehnder method.

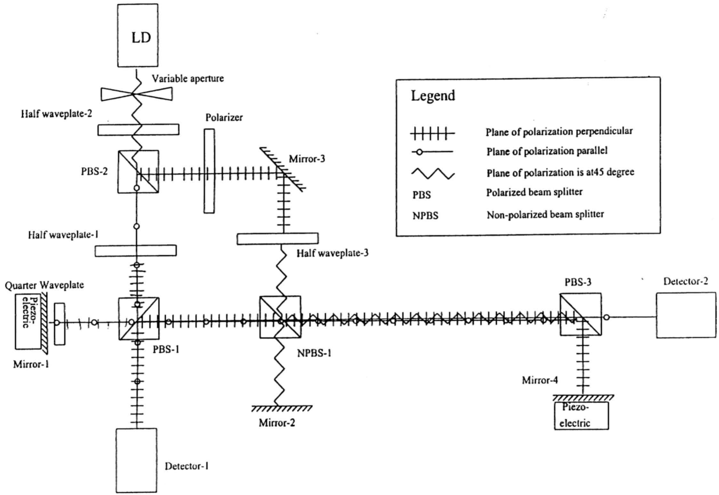


Fig. 6.15 Components arrangements for single channel two-way communication system, using Michelson technique.

The other part of the light-wave is again divided into two parts by a non-polarizing beam splitter (NPBS-2), each of which works as a reference light-wave, one for the outgoing signal and the other for an incoming signal. The outgoing polarization plane of reference light-wave is adjusted to 45^0 with respect to the plane of polarization of the outgoing signal light-wave. Both light-waves then (reference and signal) meet at a semi-transparent glass plate and travel in a same direction. After traveling through the free space or through the polarization-maintaining fiber both light-waves reach the receiving end where another polarizing beam splitter (PBS-2) splits the reference light-wave into two orthogonal light-waves. One of which has plane of polarization parallel to the plane of polarization of the signal light-wave while the other one is perpendicular to it. The parallel part of the reference signal helps to decode signal from a signal carrying light-wave while the perpendicular light-wave is modulated by $LiNbO_3$-2 which acts as encoder. Now this encoded light-wave is reflected by a plane mirror reaches the detector after passing through polarizing beam splitter (PBS-12). At PBS-12, two light-waves, one coming from an encoded signal and the other from a local reference light-wave signal, are aligned in the same plane before reaching the detector. The detector is able to decode the signal due to the interference between these two light waves of same plane of polarization.

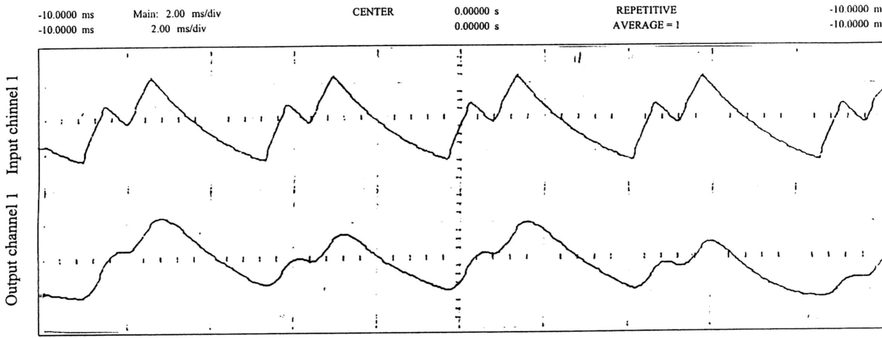
Similar system can be design by utilizing the Michelson technique. In this design two quarter-wave-plates are used, shown in the Fig. 6.15. In this system optical signals are encoded by vibrating mirrors through piezo-electric elements. Mirror-1 is used for sending messages while mirror-4 is used for sending a message back to the laser source side. In the diagram shown in Fig. 6.15 a diode laser is used as light-source which emits polarized light with an extinction ratio less then 1%. Polarization of a laser diode is very stable, which is one of the basic requirements for phase shift keying (PSK) communications. A variable aperture is used to control intensity of light. Plane of polarization is rearranged by using half-wave plate and it is also used to change the relative intensity of light wave reflected and transmitted through polarizing beam splitter (PBS-2). PBS-2 splits light wave into two orthogonal polarized beam. One portion of the light-wave, which is reflected by mirror-3, is used as reference and another portion of the light wave passes through the second half waveplate-2. This waveplate rotates the plane of polarization by 90^o and reflected toward quarter waveplate by polarized beam splitter (PBS-1). After passing through the quarter wave plate the lightwave is reflected back by mirror-1 attached to the piezoelectric. This piezoelectric is used to increase and decrease the path length of lightwave, therefore creating phase modulation. After this light wave is reflected from the mirror-1 it goes to detector-2. Since it has passed through the quarter waveplate twice which creates a 90^0 phase shift, this light-wave will be attenuated by the non-polarizing beam splitter (NPBS-1). The second portion of the lightwave the reference lightwave from PBS-2, pass through the polarizer which is oriented in the same plane. This polarizer actually blocks any back reflection from mirror-2. Half-wave plate-3 is used for rotating polarization plane by 45^0. The reference light wave is split into two parts where one portion is reflected by the non-polarizing beam splitter (NPBS-1) and the other passes through. On the receiving end, the reference light wave is again split into two. The plane of polarization of one light wave is parallel to the plane of polarization of the signal wave, which is reflected by mirror-1 and the other light wave is perpendicular to it.

Signal encoded by mirror-1 is detected by detector-2. The remaining portion of lightwave is used for sending message back to the source side using vibrating mirror-4 which is attached to a piezo-electric element. The encoded light wave is mixed with a portion of reference light wave, which is reflected by the fixed mirror-2, and this signal is detected by detector-1. Hence a two-way communication is established. One thing to be very careful of is coherence length, which limits mirror-1 very close to PBS-1 otherwise an additional path length or time delay [2] would have to be added for the reference light wave. Similarly the path length of the second reference light which is reflected by mirror-2 should be the same as signal carrying light wave coming back from the other side which is away from the laser.

6.3.1 Results

Though two systems have been designed, only the second one is used for obtaining most of the results, which is given here. Fig. 6.16 and Fig. 6.17 are input and output signals respectively. The input signal is on the laser side while output is on the other side. From the diagram we can clearly see that output signal is a replica of input signal with some exceptions. Due to inertia of mirror-1 the oscillogram edges are rounded and there is some time delay between input and output. This delay is caused by the input generated by the physical displacement of the mirror. The difference between Fig. 6.16 and Fig. 6.17 is the placement of slits on the detector area, which can invert the shape of the output signal. Fig. 6.18 also shows the input and output signal, but with the output signal is on the source side and input is from the other side, which is away from the diode laser. Again output signal is almost an exact replica of input signal with the previously explained exceptions. Fig. 6.19 shows two output signals when both input signals are activated simultaneously. Simultaneous input signals are shown in Fig. 6.20. On comparing these two figures it is same that there is no interference between the two output signals. Both output signals are independent of each other. This clearly shows that in a single channel two-way phase modulation communication is possible with no interference between the channels.

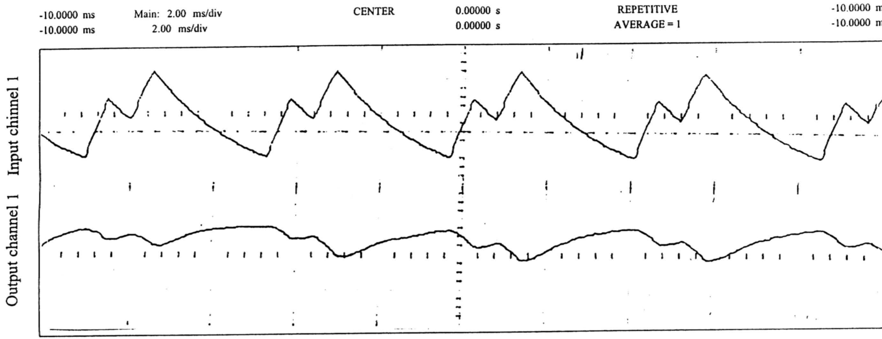
This system has a few advantages over other communications systems. Detectors are most sensitive for phase modulation, which allows a lower light-wave intensity required for the communication systems with the same BER (BER = 10^{-9}). Since this is an all optic system, which makes it quite independent of bit rate. This system does not use any active element, which makes it quite easy to maintain but there is a drawback into the system it is dependent on the proper value of coherence length. In this system the correct coherent length is maintained by placing mirror-1 and mirror-2 at a proper distances from PBS-1. The variable delay device can be used for the coherence length and is most suitable for these types of experiments. With the precise delay, coherence length can be adjusted such that different sources can be selected depending on their location, meaning different path lengths will match with different coherence lengths. The receiver will be able to decode only one signal, when a matching coherence length is found all other signals will be ignored.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	400 mV/div	950.000 V	1:1	dc	1M ohm
Channel 2	10.0 mV/div	260.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 750.000 mV (noise reject OFF)
Holdoff = 40.000 ns

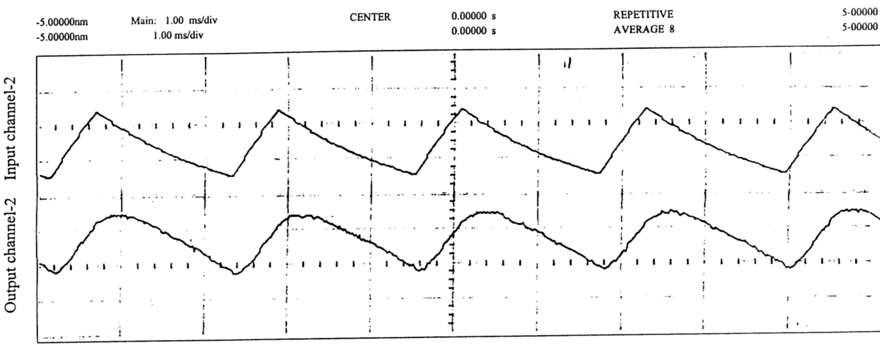
Fig. 6.16 Input and output signal for channel-1, by utilizing a single channel two-way communication system as shown in Fig. 6.15



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	400 mV/div	950.000 V	1:1	dc	1M ohm
Channel 2	10.0 mV/div	287.500 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 750.000 mV (noise reject OFF)
Holdoff = 40.000 ns

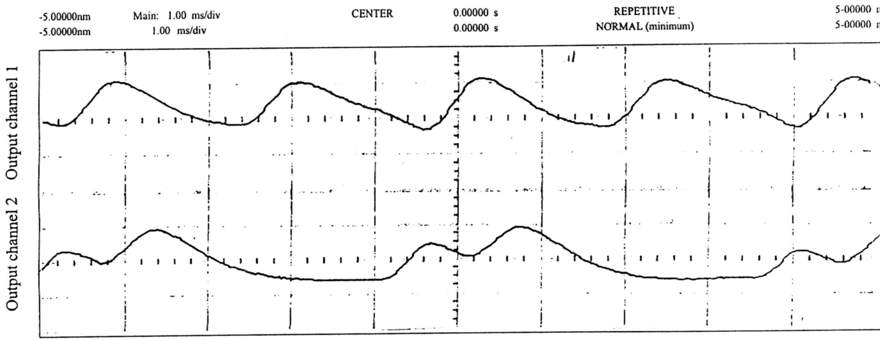
Fig. 6.17 Input and output signal for channel-1, by utilizing a single channel two-way communication system as shown in Fig. 6.15 but in this case the slits are placed in such a way that when no signal is applied all bright fringes are blocked.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	400 mV/div	1.20000 V	1:1	dc	1M ohm
Channel 2	4.00 mV/div	278.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive Edge of Channel 1
Trigger Level (s)
Channel1 = 1.19500 V (noise reject OFF)
Holdoff = 40.000 ns

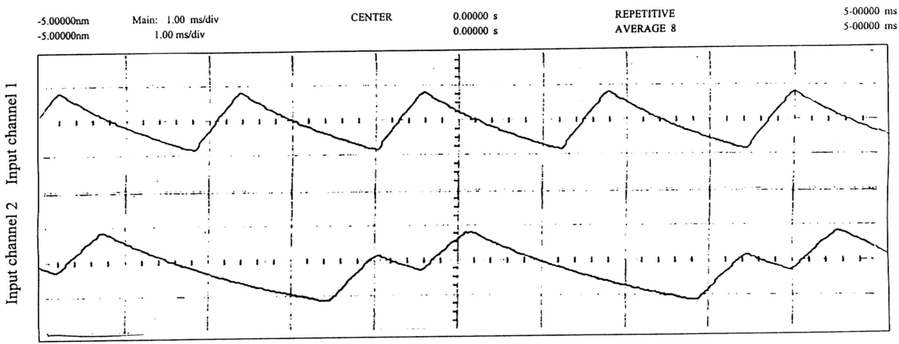
Fig. 6.18 Input and output signal for channel-2, by utilizing a single channel two-way communication system as shown in Fig. 6.15.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	10.0 mV/div	278.000 V	1:1	dc	1M ohm
Channel 2	10.0 mV/div	280.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 282.000 mV (noise reject OFF)
Holdoff = 40.000 ns

Fig. 6.19 Two output signals when both in channels are activated.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	400 mV/div	962.500 V	1:1	dc	1M ohm
Channel 2	400 mV/div	937.500 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the pPositive Edge of Channel2
Trigger Level (s)
Channel1 = 1.13350 V (noise reject OFF)
Holdoff = 40.000 ns

Fig. 6.20 Two input signals for a single channel two-way communication system, using the Michelson technique as shown in Fig. 6.15

6.4 All Optical Single Channel, Two-Way Communication, Utilising A Single Light Source Without A Time Delay Unit

In this system polarized light wave from the laser diode is divided into two parts, one of which is used to carry signal and the other is used as a reference. When these two light waves reach the receiver, the reference light wave is divided further into two components. One of which has its plane of polarization parallel to the plane of polarization of the signal light and the other part is again split into two parts, one of which is encoded with information, then both signals are reflected back towards the source. At the source side, the in-coming signal can be decoded by mixing it with the portion of the back-reflected reference light wave. This completes a two-way communication system. In this system no time delay unit is used. This system can be designed in two different ways, one using a Michelson interferometer and the other using a Mach-Zehnder technique. Both designs are given below.

6.4.1 System Design Using Michelson Technique

In this design the elliptical cross section of laser diode (LD) beam which is partially polarized is changed into plane polarized light with a polarizer. This plane of polarized light is arranged, with respect to polarizing beam splitter (PBS-2), in such a way that the beam splitter splits the light into two unequal orthogonal planes. Intensity ratio of these two light waves depends on the polarization angle of light with respect to the beam splitter's plane, the polarization quality as well as the beam splitter quality. The component of light wave that goes straight, passes through another polarizing beam splitter (PBS-1) after which it goes through a quarter waveplate.

Behind the quarter wave plate there is plane mirror-1 which is attached to a piezoelectric element as shown in Fig. 6.21. Light is reflected back by mirror-1 after passing through the quarter waveplate which changes the plane polarized light wave into circularly polarized light wave. But on the way back this circularly polarized light again passes through the quarter waveplate and the circularly polarized light changes into a plane polarized light. This time the plane of polarization is orthogonal to plane of polarization of the incident light on the PBS-1. This plane polarized light is reflected toward the non-polarizing beam splitter, NPBS-1. A Piezoelectric element is used to encode signal onto this reflected light wave. This signal carrying light wave is mixed with the reference light wave, which has plane of polarization at 45^0 to the plane of polarization of the signal carrying light wave.

Rotation of plane of polarization is done via a half waveplate, HWP-1. These two light waves, reference and signal pass through free space or polarization-maintaining fiber. On the receiving end, a polarizing beam splitter (PBS-3) separates the signal carrying light wave. PBS-3 also splits the reference light wave into two orthogonal plane polarized light waves, one of which has a plane of polarization parallel to the plane of polarization of the signal light wave. By mixing of these two parallel light waves, signal and part of a reference, the signal can decoded.

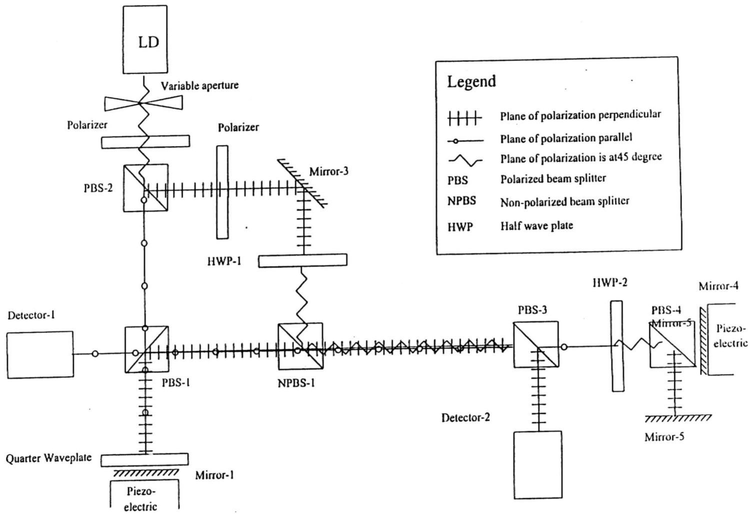


Fig. 6.21 Components arrangements for single channel two-way communication system, without using time delay unit, using Michelson technique.

The remaining part of the reference light is again split into two parts by a combination of half wave plate (HWP-2) and polarizing beam splitter-2. HWP-2 rotates the light wave polarization to a certain angle, which is then split into two parts and both parts are reflected back by two plane mirrors. Mirrors are placed perpendicular to the direction of light. Mirror-4 is attached to a piezoelectric element. This is used for encoding signal while mirror-5 remains stationary and can just reflect the in-coming light wave back. This part of light is called the reference light wave. When these two light waves reach the source side then these light waves are detected by detector-2. A similar design can be developed by using the Mach Zehnder technique, which is given below.

6.4.2 System Design Using The Mach Zehnder Technique

One channel two-way communication can also be achieved utilizing the Mach Zehnder method. Use of this method does not require the use of a quarter waveplate. The optical circuit of "single channel two-way communication" is shown the Fig. 6.22.

The Laser Diode (LD) beam cross section which is elliptical and is partially polarized by nature and after passing it through a polarizer, becomes a plane polarized light. But the cross section of the beam does not change. The plane of this polarized light is adjusted to 45 ^{0} with the plane of non-polarizing beam splitter (NPBS-1). NPBS-1 splits the light into two parts, one of which is reflected

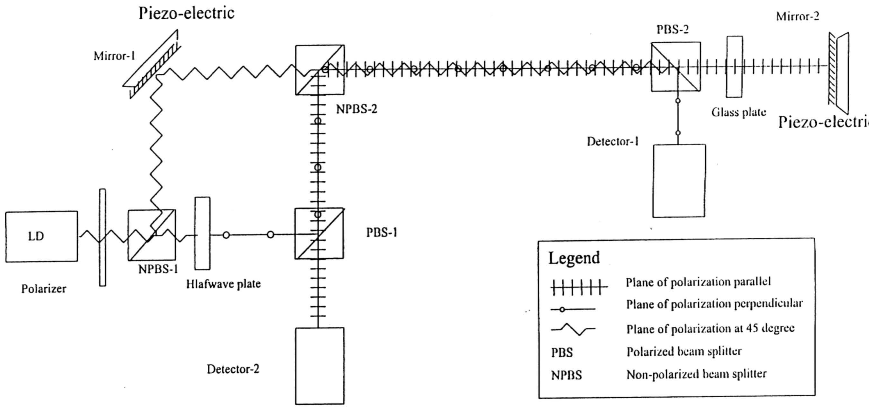


Fig. 6.22 Components arrangements for a single channel two-way communication system, without time delay unit, using the Mach Zehnder technique.

by mirror-1 and becomes the reference light wave. The other part of this polarized light is rotated by a half waveplate to adjust the plane of polarization of this light wave. Such that it is orthogonal to the plane of a polarizing beam splitter (PBS-1) so that the entire light wave is reflected by PBS-1 toward a non-polarizing beam splitter (NPBS-2). A $LiNbO_3$ crystal can be used to encode a signal on this part of the light wave. The reference light wave is mixed with the signal carrying light wave at NPBS-2 after being reflected by mirror-1. Now both light waves travel through free space or polarization maintaining fibre. New research shows that the relative polarization does not change much over few tens of kilometer length in a conventional single mode fibre [1]. This PSK communication system can be used for LAN using conventional single mode fibre. On the other side of the light source the polarizing beam splitter (PBS-2) separates signal light wave. The rest of the process is the same as explained in the first design albeit with minor changes. In the first design a piezoelectric element is used for encoding the signal which is replaced by a $LiNbO_3$ crystal in this design.

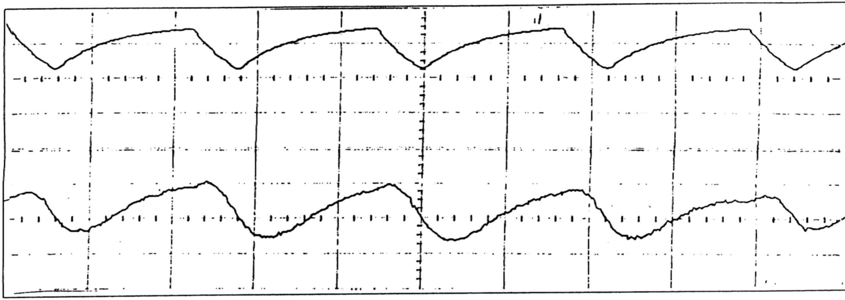
6.4.3 Result

Though there are two designs presented here and both give similar results so results from only the first are presented. Fig. 6.23 shows the input and output oscillograms for channel-1.

Signal encoded by vibrating mirror-1 and the signal detected by detector-2 is shown in Fig. 6.21 and both graphs are similar. In Fig. 6.24 the signal encoded by vibrating mirror-4 and its output is detected by detector-1 as shown. Both signals are similar indicating that the signals can be encoded and detected without any interference from each other. The two simultaneous input signals are activated by their respective piezoelectric elements which are in turn activated by their respective signal generators. This means channel-1 is activated on the laser side by vibrating mirror-1 and is detected by the detector-2 on the other side, away from the laser. Similarly a signal encoded by the mirror-4 on the other side, away from the laser is detected on the laser side by the detector-1. Both the inputs are shown in Fig. 6.25. Output wave forms of these two simultaneous inputs are shown in Fig. 6.26. If we compare these two input signals versus the two respective output signals we can see that output signals are replicas of the inputs except for sharp edges of input waves which are broadened in the output. This is due to inertia of the mirrors. Sometimes the output signal is a multiple of the input signal and the multiplying factor depends on the amplitude of the mirror's vibration or phase difference created by mirror (or $LiNbO_3$ if used). If the phase difference created by the piezo-electric is one-wavelength then two crests or two troughs are created on the surface of the detector. This is clearly shown in Fig. 6.27 where the output signal frequency is double the input frequency. The shape of the output graph also depends on the position of the slit on the detector. In Fig 6.28 slit position for channel two is such that we get inverted output for channel-2 while output of channel-1 is not-inverted. In this case the slit for channel-2 output is placed at the bright fringes (bright fringes pass through the slit when no signal is applied). So when a signal is applied the bright fringes move and are blocked so the detector detects a minimum intensity, in other word it inverts the incoming signal.

The polarizing beam splitter is also sensitive to the orientation of the plane of polarization i.e. if the polarization plane of the incident light is parallel to one of PBS-2 planes the light will either be all transmitted or all reflected. But if the angle of the plane of polarized light is other than that described above then the light intensity will be split depending on the angle. Which means that by controlling the polarization angle with respect to the horizontal, the splitting ratio can be controlled. In this experiment the intensity of light wave is divided into reference light and signal light with a 1:9 ratio, where 10% of the light pass through while the remaining 90% becomes the reference light wave and this reference is rotated by a half-waveplate by an angle of 45° after which it is reflected towards NPBS-1 where it is combined with the signal light wave. The 10% light is reflected back by mirror-1. If this signal carrying light-wave travels over a longer distance then the reference light-wave will create problems related with coherence length. Therefore the mirror and the quarter waveplate are placed very close to beam splitter PBS-1 to reduce the path length difference between the two light-waves. If it is not possible to place mirror-1 very close to PBS-1 then an additional path length difference has to be created using double right angle prisms as done in one of the previous experiments. Similar arrangements have to be made on the receiving side (away from the source). But it is easier to do so on the other side because mirrors can independently be placed and coherence length can be adjusted.

-5.00000nm	Main: 1.00 ms/div	CENTER	0.00000 s	REPETITIVE	5-00000 ms
-5.00000nm	1.00 ms/div		0.00000 s	NORMAL (minimum)	5-00000 ms

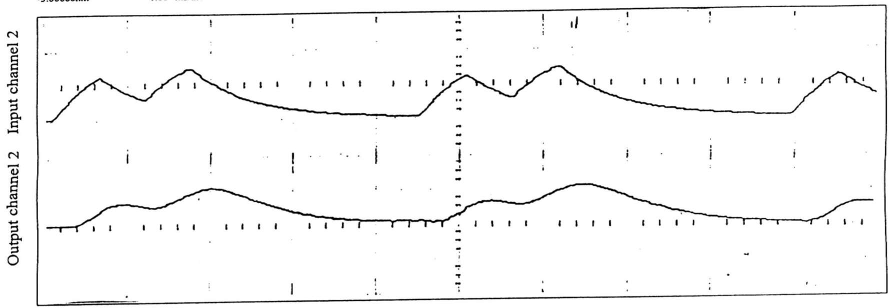


	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	2.00 V/div	1.43750 V	1:1	dc	1M ohm
Channel 2	4.00 mV/div	209.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 1.97750 V (noise reject OFF)
Holdoff = 40.000 ns

Fig. 6.23 Input output graph for channel-1 for single channel two-way communication system.

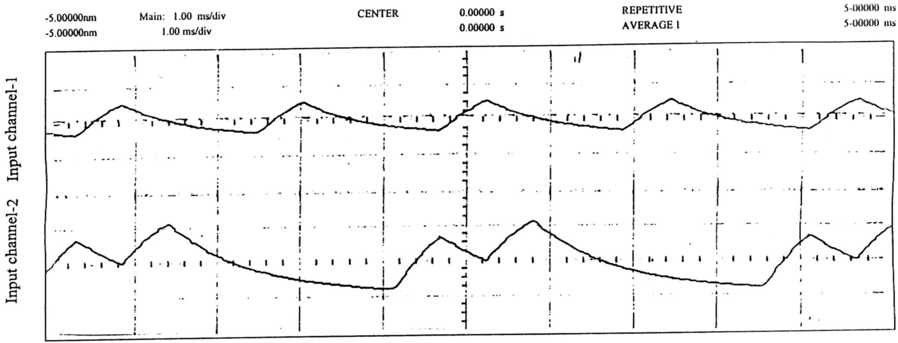
Input is on the laser side and output is on the other side, away from laser, as shown in Fig. 6.21



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	2.00 V/div	2.00000 V	1:1	dc	1M ohm
Channel 2	20.00 mV/div	220.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 2.00000 V (noise reject OFF)
Holdoff = 40.000 ns

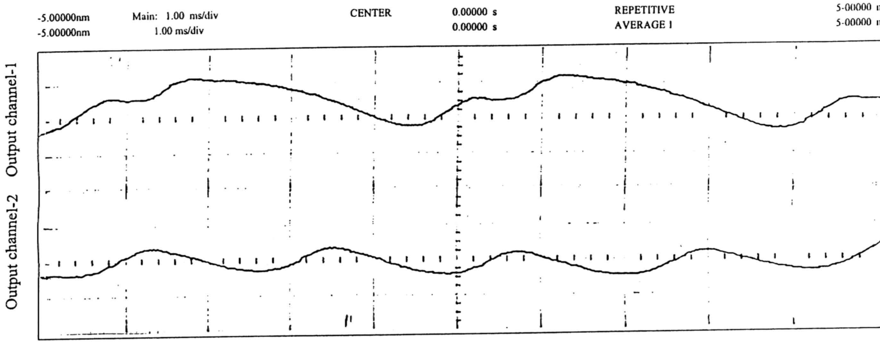
Fig. 6.24 Input output graph for channel-2 for single channel two-way communication system.
Output is on the laser side and input is on the other side, away from the laser



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	2.00 V/div	962.600 mV	1:1	dc	1M ohm
Channel 2	1.00 V/div	937.600 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive Edge of External
Trigger Level (s)
Channel1 = 1.13800 V (noise reject OFF)
Holdoff = 40.000 ns

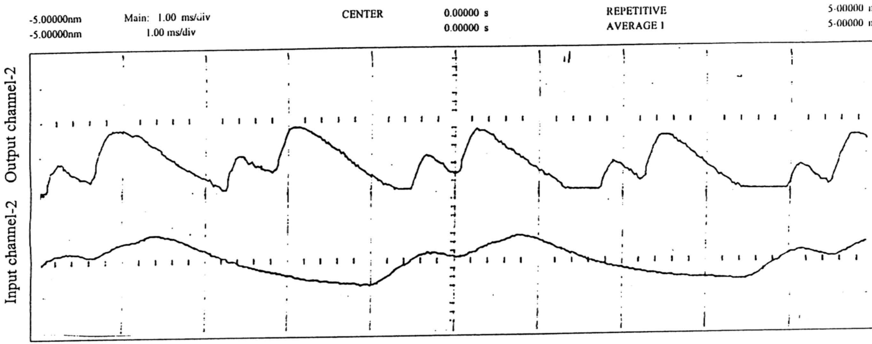
Fig. 6.25 Graph for two simultaneous inputs of out going signal as channel-1 and incoming signal as channel-2



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	10.0 mV/div	223.000 mV	1:1	dc	1M ohm
Channel 2	10.0 mV/div	225.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive Edge of External
Trigger Level (s)
Channel1 = 226.000 nV (noise reject OFF)
Holdoff = 40.000 ns

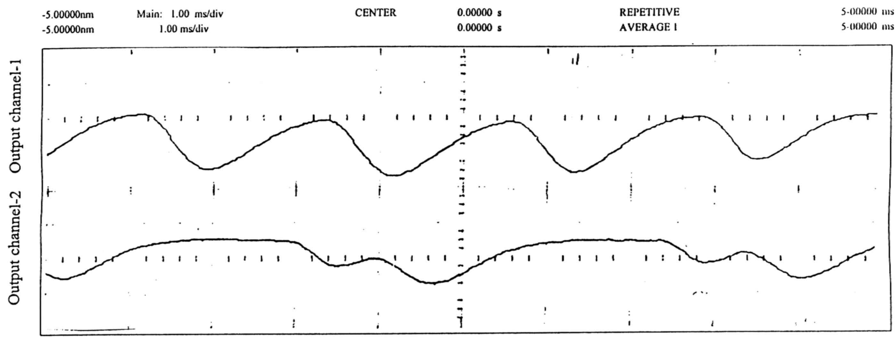
Fig. 6.26 Graph for two simultaneous outputs. Output detected as channel-1 is at detector-2 and output detected as channel-2 is at detector-1 as shown in Fig. 6.21



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	4.00 mV/div	212.000 mV	1:1	dc	1M ohm
Channel 2	10.0 mV/div	212.500 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive Edge of External
Trigger Level (s)
Channel1 = 234.000 mV (noise reject OFF)
Holdoff = 40.000 ns

Fig. 6.27 Graph for input channel-2 and output channel-2. Output channel-2 is on the laser side and input is away from the laser. Output frequency is double of input frequency.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	10.0 mV/div	272.000 mV	1: 1	dc	1M ohm
Channel 2	10.0 mV/div	255.000 mV	1: 1	dc	1M ohm

Trigger Mode: Edge
On the Positive Edge of External
Trigger Level (s)
Channel1 = 298.000 m V (noise reject OFF)
Holdoff = 40.000 ns

Fig. 6.28 Graph of two output singals, when the two inputs are applied simultaneously.

6.5 All Optical Two Channels, Two Ways PSK Communication, By Using Single Light Source

In this system polarized light is divided into three parts. Two of which have their plane of polarization orthogonal to each other and the third used as a reference light wave, has its plane of polarization at an angle of 45° to both the other two. Signals are encoded on both the orthogonally plane polarized light. When all these three light wave reach on the other side (on receiving end, away from light source) polarizing beam splitter (PBS-15) separates the two orthogonal plane polarized lights as well as splitting the reference light wave in two orthogonal light waves. Both signals are decoded from the signal carrying orthogonal light by interfering them with their respective orthogonal reference light wave. A portion of both of these light waves can be reflected back towards the light source with coded signals. Coding must be done in such a way that the received signals are subtracted electronically before being sent back towards the light source, otherwise coming back signal will have a portion of the signal which was sent from the source. When these signals are received at the source side they are pure signals without any interference [3]. Since this can be done to both the orthogonally polarized light, two-way two-channel communication can thus be established. As before there are at least two different ways to design such a system one using Mach Zehnder's method and the other using Michelson's method. But here the "two-way two-channel phase modulated communication system" will only be demonstrated using Mach Zehnder's method which is easier and has less interference.

6.5.1 Experiment

The cross section of the light beam emitted from the laser diode is elliptical which is also partially polarized. When this light wave passes through a polarizer it becomes plane polarized. This plane polarized light passes through a non-polarizing beam splitter NPBS-3 which splits the light wave into two parts one of which passes through and becomes the reference light wave while the other light wave is split again into two by a polarizing beam splitter PBS-4 into two orthogonal plane polarized waves. Each of these light waves is reflected by mirrors M-5 and M-9. These mirrors are attached to piezoelectric elements and act as sources of input signals as shown in the Fig. 6.29.

Polarizing beam splitter PBS-7 combines both of these light waves but these do not interfere with each other because the plane of polarization is orthogonal to each other. These signals carrying light waves are combined with the reference light wave by the non-polarizing beam splitter NPBS-14. The polarization plane of the reference light wave is 45^0 to the polarization plane of both the signal light waves. All three lightwaves travel through free space and at the receiving end, away from the light source, a polarizing beam splitter (PBS-15) separates the two orthogonal signal carrying light waves. This polarizing beam splitter also splits the reference light wave into two orthogonal light waves. The signals are decoded at the detector by interference of signal light wave and its respective reference light wave, these signals are detected by detectors D-22 and D-25. Before reaching these detectors, each light wave pass through half-wave plate P-16 and

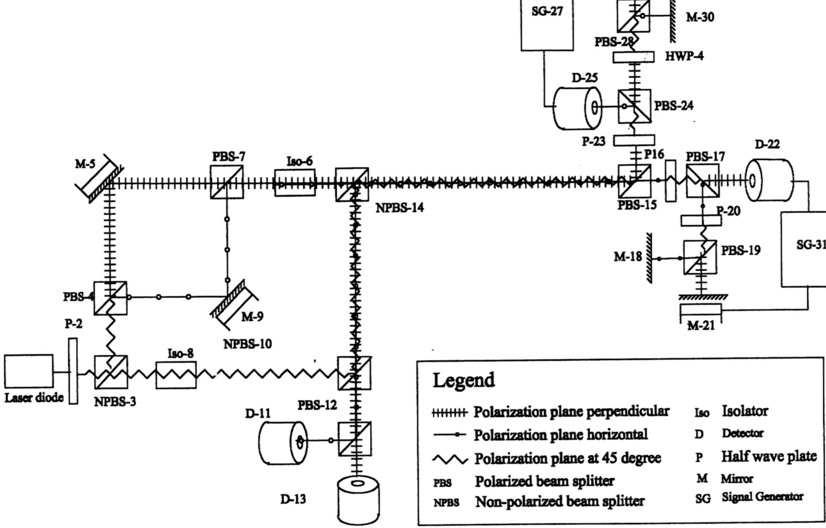


Fig. 6.29 Component arrangement for two-channel two-way communication system, using a single light source

P-23. These half-wave plates change the plane of polarization of these waves. The light wave, which passes straight through PBS-15 and P-16, is again divided into two unequal parts by polarizing beam splitter PBS-17. A portion of this light-wave which passes through is detected by detector D-22. The signal, encoded by mirror M-5, is detected by D-22. Now, the remaining portion of this signal-carrying wave, which is reflected by PBS-17, reaches the surface of mirror M-21 which is attached to a piezo-electric element. Receiver D-22 also has message transmitted by M-5.

If need arises to send a signal to the laser side it can be encoded by mirror M-21. But since mirror M-21 is also receiving message so the actual message encoded by mirror M-21 should be the real message minus the received message which can be achieved electronically just like subtracting two signals in oscilloscope.

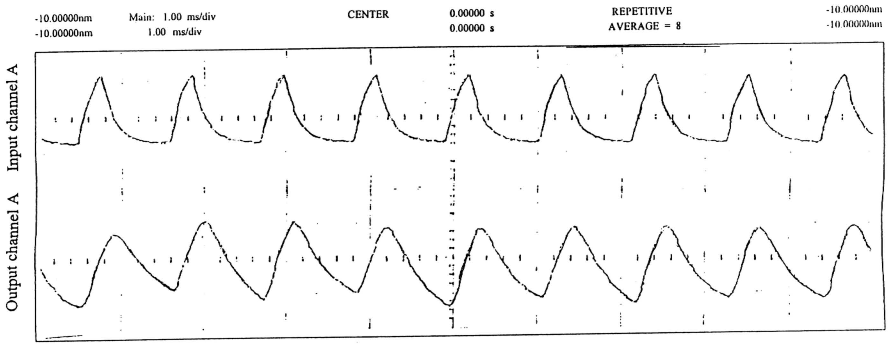
This signal is reflected back to the light source side and it reaches to non-polarizing beam splitter NPBS-10. There is another signal reaching from mirror M-29 but this signal is orthogonal to the signal coming from M-21. After passing through NPBS-10 both these signals coming from different mirrors are separated by polarizing beam splitter PBS-12. The signal encoded by the mirror M-21 is detected by detector D-13 and signal encoded, in a similar way, by mirror M-29 is detected by detector D-11. Both signals bring their own reference light wave because not the whole reflected light wave is encoded by the signal and a portion of light wave is reflected back without any signal. This portion of light wave acts as reference light wave for the coming-back signals. These reference light waves are reflected back by mirror M-18 and mirror M-30. An isolator ISO-6 is placed between PBS-7 and NPBS-14 to block a portion of the signal from reaching the light source. Similarly another isolator ISO-8 is placed between PBS-10 and NPBS-3. This isolator also protects the light source from back reflection. Both isolators isolate light source from any kind of light wave coming form the other end of the system.

6.5.2 Results

This system has four channels the first of which will be termed channel A contains mirrors M-5 and detector D-22. The second channel is channel B and contains mirror M-9 and a detector D-25. Both these mirrors are attached to piezoelectric elements and act as signal encoders and are situated on the light source side while their respective detectors are on the other side, away from the light source side as shown in Fig. 6.29.

Similarly, channel C contains mirror M-21 and detector D-13 and channel D contains mirror M-29 and detector D-11. Both of these inputs are on the other side of the light source.

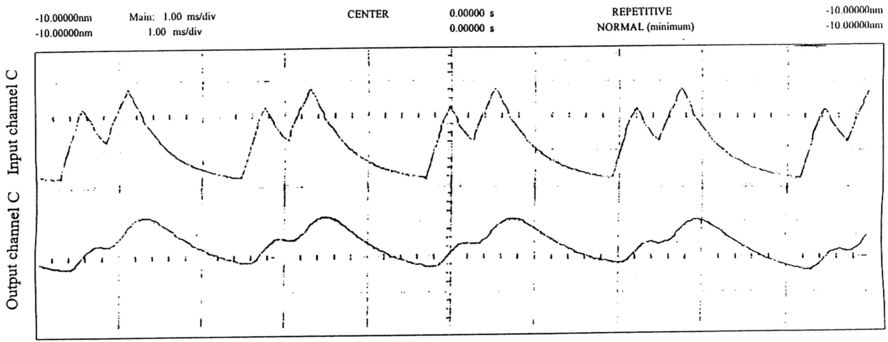
First, channel A is activated by vibrating mirror M-5, while channel-C is not activated. The detector D-22 detects an output signal. Input output graph of channel-A is shown in Fig. 6.30. The graph shows that the output signal is a replica of the input signal except for output peaks which are broadened and there is some time delay. Both are due to the inertia of mirror M-5. In this case the input signal is taken just after the piezoelectric driver.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	2.00 mV/div	1.50000 V	1:1	dc	1M ohm
Channel 2	4.00 mV/div	229.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 1.50000 V (noise reject OFF)
Holdoff = 40.000 ns

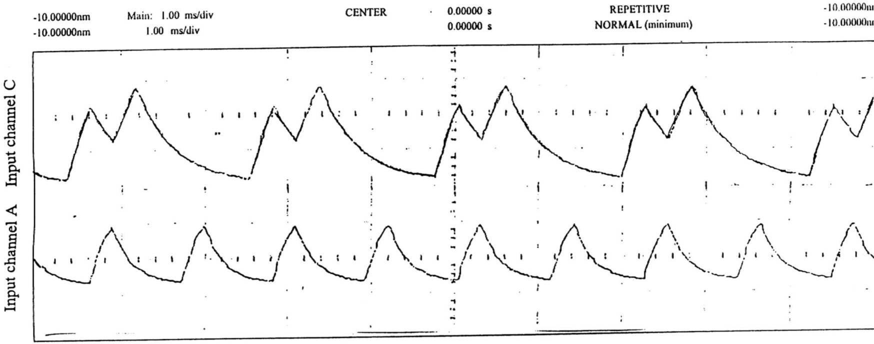
Fig. 6.30 Input output graph for channel A, using M-5 as signal encoder and D-22 as detector, as shown in Fig. 6.29, channel C is not active.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	1.00 mV/div	2.00000 V	1:1	dc	1M ohm
Channel 2	20.00 mV/div	215.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 2.00000 V (noise reject OFF)
Holdoff = 40.000 ns

Fig. 6.31 Input output graph for channel C using mirror M-21 as signal encoder and D-11 as detector while channel A is not active, as shown in Fig. 6.29.

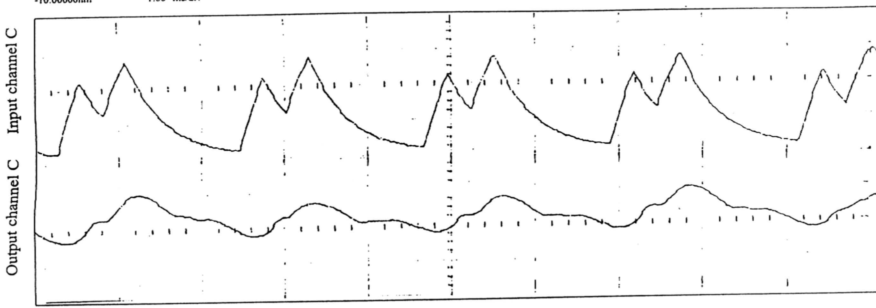


	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	1.00 mV/div	2.00000 V	1:1	dc	1M ohm
Channel 2	20.00 mV/div	1.50000 V	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 0.00000 V (noise reject OFF)
Holdoff = 40.000 ns

Fig. 6.32 Graph for two simultaneous inputs for channel A and channel C, in which both channels have same plane of polarization but travel in opposite directions.

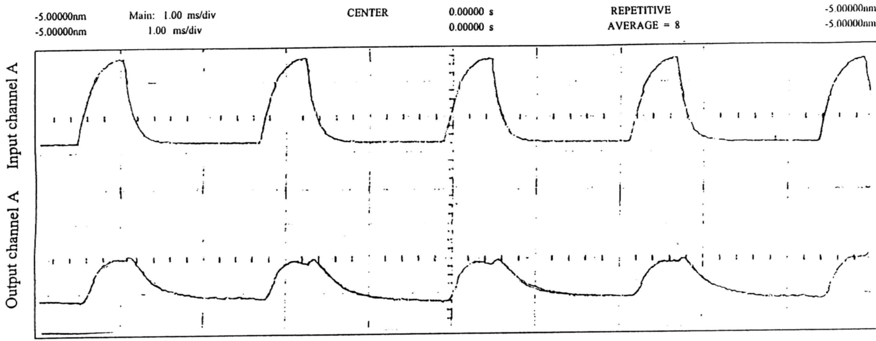
-10.00000nm Main: 1.00 ms/div CENTER 0.00000 s REPETITIVE -10.00000nm
-10.00000nm 1.00 ms/div 0.00000 s NORMAL (minimum) -10.00000nm



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	1.00 mV/div	2.00000 V	1:1	dc	1M ohm
Channel 2	20.00 mV/div	215.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 2.00000 V (noise reject OFF)
Holdoff = 40.000 ns

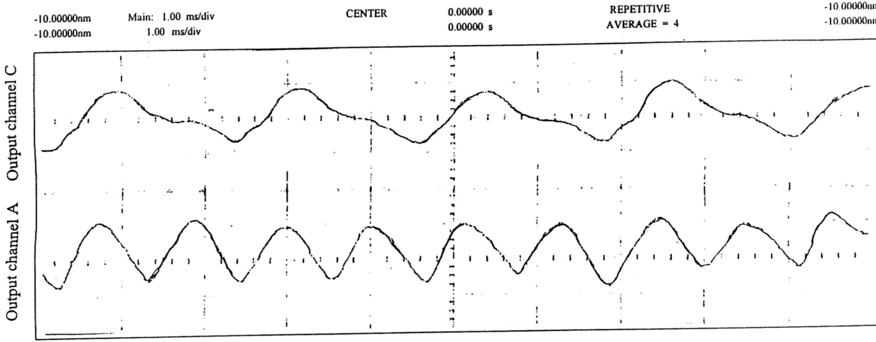
Fig. 6.33 Input output graph of channel C when channel A is also activated. Mirror M-21 is used as input for channel C and output of channel C is detected by the detector D-13. Output singal is not an exact replica of input signal.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	2.00 mV/div	1.50000 V	1:1	dc	1M ohm
Channel 2	4.00 mV/div	296.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 1.50000 V (noise reject OFF)
Holdoff = 40.000 ns

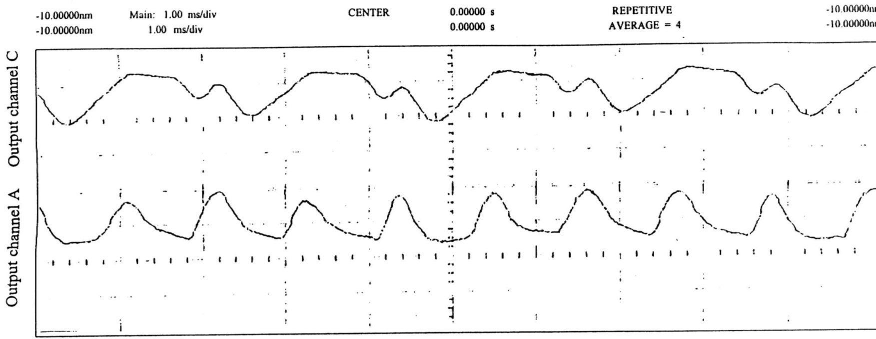
Fig. 6.34 Input output graph for channel A, using M-5 as signal encoder and D-22 as detector, as shown in Fig. 6.29, with channel C is actived.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	10.00 mV/div	210.000 mV	1:1	dc	1M ohm
Channel 2	4.00 mV/div	210.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 210.000 V (noise reject OFF)
Holdoff = 40.000 ns

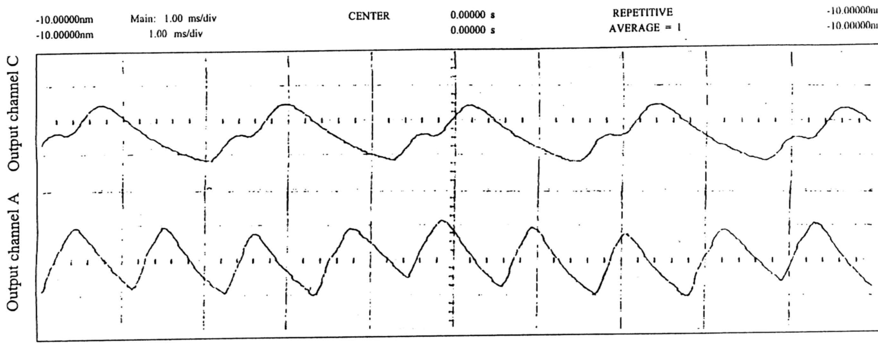
Fig. 6.35 Graphs of two outputs channel A and channel C when both channels are activated simultaneously. Output of channel C contains portion of signal from channel A.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	10.00 mV/div	225.000 mV	1:1	dc	1M ohm
Channel 2	4.00 mV/div	320.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 225.000 V (noise reject OFF)
Holdoff = 40.000 ns

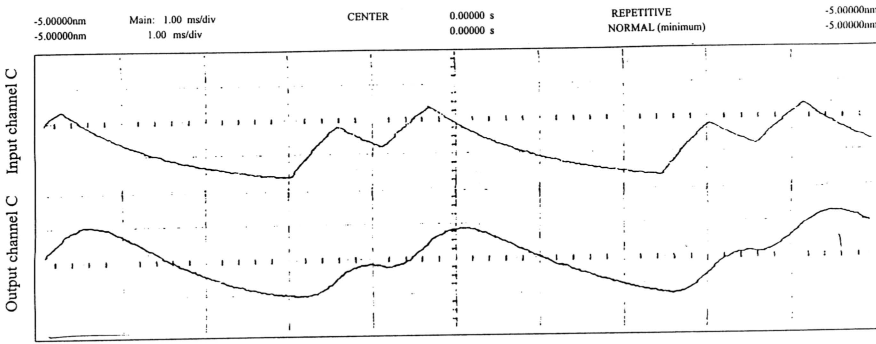
Fig. 6.36 Graphs of two outputs channel A and channel C when both channels are activated simultaneously. Output of channel C contains portion of signal from channel A. Here intensity of channel A is increased



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	10.00 mV/div	215.000 V	1:1	dc	1M ohm
Channel 2	10.00 mV/div	215.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 216.000 V (noise reject OFF)
Holdoff = 40.000 ns

Fig. 6.37 Graphs of two outputs channel A and channel C when both channels are activated simultaneously. When the effect of channel A is removed from the channel C.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	1.00 mV/div	2.00000 mV	1:1	dc	1M ohm
Channel 2	10.00 mV/div	230.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive edge Channel 1
Trigger Level (s)
Channel 1 = 2.00000 V (noise reject OFF)
Holdoff = 40.000 ns

Fig. 6.38 Input output graph of channel C when both channels are activated simultaneously. When the effect of channel A is removed from the output of channel C.

In Fig. 6.29 vibrating mirror M-21 activates channel-C and detector D-13 detects it when channel A is not activated which means mirror M-5 is not vibrating. Again the output signal is like the input signal as shown in Fig. 6.31.

When both channel-A and channel-C both are activated, by vibrating mirror-5 and mirror-21, simultaneously then both send different signals in opposite directions but in the same plane of polarization. The two input signals are shown in Fig. 6.32, upper graph is for channel C while lower graph is for channel A. Relative peak positions for both differing signals are fixed. In Fig. 6.33 input-output graph for channel C is plotted when channel A is also activated. Mirror M-21 is used as input for channel C and detector D-11 is used as detector for channel-C. Output of channel-C is not an exact replica of input channel C. Infact output of channel-C contains a portion of input signal of channel A. This is because mirror M-21 at channel-C is reflecting back the light wave which contains signal from channel A.

In Fig. 6.34 input output graph is plotted for channel A when channel C is also activated. In this case the output signal is similar to input signal. There is no interference of channel C into channel A. This is obvious because input of channel A does not contain any portion of signal from channel C.

There is a small kink in the output graph channel A. It is due to the higher vibration amplitude of mirror M-5, the vibration amplitude is increased further then the single peak will split into two similar peaks.

Fig. 6.35 graphs outputs from channel A and Channel C. When the two channels are activated simultaneously, presence of output signal from channel-A is obvious in output graph of channel-C. This can be seen due to the relative positions of the peaks which are fixed as shown in Fig. 6.32.

Fig. 6.36 graphs outputs of channel A and channel C. Output graphs of channel C is not a replica of its input signal, which is also shown in Fig. 6.32. The difference between Fig. 6.35 and Fig. 6.36 is that the relative intensity is changed. Now the effect of channel A on channel C is more obvious.

In Fig. 6.37 oscillogram of outputs for channel A and channel C are shown. This time effect of channel A is already removed from the output of channel C by re-alignment of mirrors. Now we can see that the output signals are replica of their respective input signals.

Fig. 6.38 shows input and output graph of channels C when the effect of channel A is removed. The output signal of channel C is an exact replica of its input. Channel B and channel D behave almost exactly as channel A and channel C. The only difference is that these channels have their plane of polarization perpendicular compared to the plane of polarization of channel A and channel C. Channel A does not interfere with channel B or channel D because of this polarization difference. Similarly, the same also applies to Channel C with channel B or channel D. On the other hand there is a chance of interference between channel A and channel C because their plane of polarization is the same.

This has been discussed before. Similarly interference of channel B and channel D is there but since it is exactly like set of channel A and channel C so it gives exactly similar results.

In the experiments subtraction of the signal was achieved just by misalignment. But in the case of fiber optic communication this has to be done electronically which, however, is not very difficult to do. The amount of signal subtracted depends on the intensity of input signal with respect to intensity of the reference light wave. Since PSK communication is coherence length dependent so the difference in path length between the reference light wave and the respective signal light wave must not exceed coherence length of the source used.

6.6 Coherence Length Dependent Multi-Channel PSK Communication System Using A Single Light Source

Light waves of the same frequency and of the same plane of polarization do not interact if their path length difference is more than the coherence length. Using this property it is demonstrated that more than one channel can be transmitted as long as the difference in their path lengths is more than the coherence length of the light source used.

In the last few experiments many types of phase shift keying (PSK) communications techniques were demonstrated. But all PSK communications are coherence length dependent, which means that for decoding a signal path difference between two light waves, the signal carrying light wave and reference light wave, must have a path difference within the coherence length. If the path length difference is more than coherence length then decoding of signals is not possible.

There are three basic conditions for PSK communication. First is that the light wave must have a very stable frequency with a very narrow line-width. Second, all the interacting light must have the same plane of polarization and this plane of polarization must be stable, which rules out most gas laser system for use as a light source for PSK communication because their plane of polarization tends to change with time. The third condition, which usually applies only to PSK communication, is that coherence length or coherence time. In most of light sources the phase of light wave changes randomly and this give rise to a coherence time or coherence length. In the case of direct detection / intensity modulation (DD/IM) and frequency modulation (FSK) a change of phase does not affect the communication system, but in the case of PSK change of phase is very important since it may change a zero bit to a one or a one bit to a zero, therefore PSK system with interacting light waves must be within the coherence length limit.

For coherent communication the medium through which the signal lightwave passes must be polarization maintaining [4]. This can be free space or polarization maintaining fiber (PMF). There are two kinds of polarization maintaining fibers. First is one which maintains the plane of polarization in two dimensions, in which both plane of polarization are maintained. If fiber has perfect cylindrical geometry and it is not birefringent then this type fiber can maintain two plane of polarization. It is already been demonstrated "one way two channel PSK communication system", "two way one channel PSK communication system", and " two ways two channel PSK communication system" in free space. If such communication systems are used then all optical fibers and couplers must be polarization maintaining in two dimensions but this type of PMF are very difficult to make and is very expensive.

There is another kind of PMF, which maintains plane of polarization only one axis. This kind of PMF usually has elliptical area of cross-section. It is easier to make and is cheaper than the first one. In our present design we can use second type of PMF and can still have more than one channel. In the following design we have used this coherent length properties for sending more information over same space.

6.6.1 Experiment

In this experiment laser diode is used here as light source. A variable aperture is used to control the intensity of light while half-wave plate is for reorienting the plane of polarization. Polarized beam splitter (PBS-1) is used for monitoring the power of light wave most of light wave simply pass through (PBS-1). Component arrangements for coherent dependent communication are shown in Fig. 5.39. This light wave splits into two parts by non-polarized beam splitter (NPBS). Light wave, which goes through NPBS straight, becomes reference light wave while

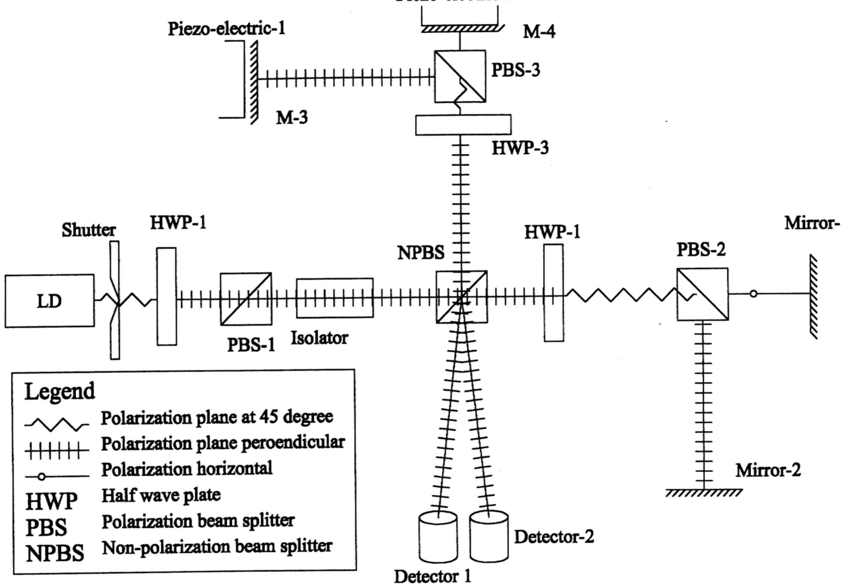


Fig. 6.39 Components arrangements for coherence length dependent PSK communication

light wave, which is reflected at 90 degree, becomes signal-carrying wave. Reference light wave is rotated by half-wave plate (HWP-2) and then again divided into two by polarized beam splitter (PBS-2). Both of these light waves which are orthogonal to each other are reflected back by the mirror-1 and mirror-2. Since these two mirrors are placed at different distance form NPBS so both have different path lengths. The light wave after being reflected by mirror-1 reaches detector-1 and light wave after reflected by mirror-2 reached at dtecctor-2.

The light wave, which is perpendicular to the reference light, is rotated by half-wave plate (HWP-3) and then divided by a polarizing beam splitter (PBS-3).
One part of the light wave goes toward the mirror-3, which is attached to piezo-electric-1, and the other part of the light wave is reflected back by mirror-4, which is attached to piezoelectric-2. These two piezo-electric elements encode independent signals on the light wave by vibrating the attached mirrors, which in turn create a phase shift. When these two encoded light waves reach their respective detectors they interact with their respective reference light wave. Path length between NPBS and mirror-1 is the same as the path length between NPBS and piez-electric-1. If this limitation is not observed the fringes on the screen will not be observed. This means that the signal-carrying light wave from piezo-electric-1 interacts with the reference light-wave coming back form mirror-1 and this is detected by detector-1. Exactly same thing occurs with a signal carrying light wave coming from piezo-electric-2, interacting with the reference light wave

coming form mirror-2 because both have equal path lengths. This signal is detected by the detector-2. In the experiments the two light wave reaching the detectors are misaligned but in the case of a real communication system the light wave can be rotated and then split into two by polarizing beam splitters. The laser diode has about 25 cm coherence length. This can be determined by using Mach Zehnder interferometer. Once the path different between light waves is more than the coherence length no interference pattern is observed. The path difference where interference becomes too dense to observe is the end of coherence length and can easily be calculated. Total path lengths form NPBS to piezo-electric-1 and back to NPBS and path lengths form NPBS to piezo-electric-2 and back to NPBS are more than twice the coherence length of the laser diode.

6.6.2 Results

This system has two channels. The first channel is denoted as channel A and contains mirror-1 and piezoelectric-2. Piezo-electric-1 acts as a signal source while detector-1 acts its corresponding detector. The second channel is denoted as channel B that has mirror-2 and piezo-electric-1 where piezo-electric-2 is used as a signal encoder and dectctor-2 acts as its detector.

Figure 6.40 shows the input-output graph for channel A. Piezo-electric-1 encodes signal and the output signal is detected by detector-1. Decoding is done by interaction of the signal carrying light wave and the reference light wave reflected back by mirror-1. This signal-carrying light wave doesn't interact with the reference light wave reflected back for the mirror-2 because these light waves have different path lengths and this difference in path is more than the coherence length of the light source used. We can see that the output is almost an exact replica of input signal except that the edges are rounded off and there is a reaction time delay is less than 0.1 ms. Fig. 6.40 is almost the same, as Fig. 6.41 except for the position of the slit used for detection is now placed on the dark fringe and because of that the output is a mirror image of the input signal.

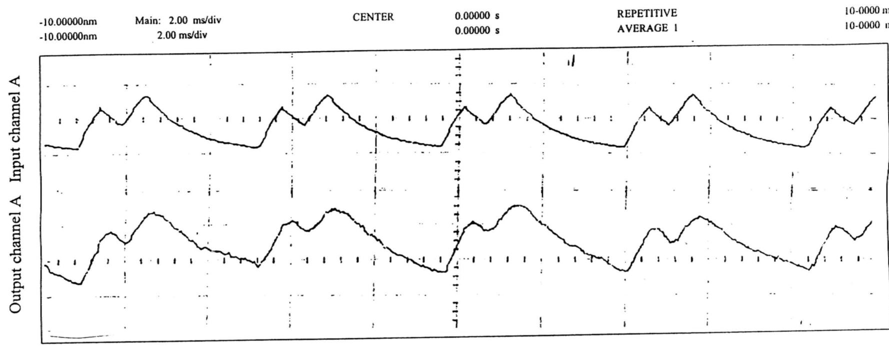
Fig. 6.42 and Fig. 6.43 are input-output graphs for channel B. In channel B piezoelectric-2 is used for encoding the signal and this signal carrying light wave interacts with the reference reflected back from mirror-4 and the output is detected at detector-2. Again this signal carrying light wave does not interact with the reference light wave reflected back by the mirror-1 due to the path difference between the two light-waves being more than twice the coherence length of the light source. In Fig. 6.42 the output, which is the lower graph, is a replica of input signal. In Fig. 6.43 the output is a mirror image of input signal due to different position of slit on the detector.

Fig. 6.44 is a graph for two input signals. These signals are applied simultaneously and the two inputs are kept constant.

Fig. 6.45 is the graph for two simultaneous output signals and the graph clearly shows that there is no interference between the two output signals.

Fig. 6.46 is also a graph for two outputs when their corresponding inputs are activated simultaneously. Output signals are exact replicas of input signals except for a lower output in and for channel B being a mirror image of the input signal.

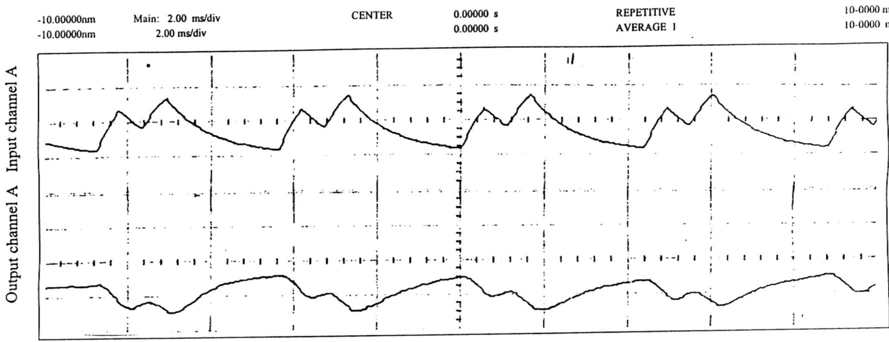
The above experiment shows that as long as the path length difference for different signal sources is more than coherence length of light source used signals will not interfere with each other. But for decoding, these signals must have reference light waves with the same path lengths as the respective signal light waves. In other words two light wave do not interfere with each other even if they have the same plane of polarization, same frequency but sufficiently different path lengths. This difference in path length must be greater than the coherence length of light source used. The above system can be used for multi-channel communications by switching it to different coherence lengths. This can be done in many different ways as reported in [2,5,6,7].



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	1.00 V/div	1.00000 V	1: 1	dc	1M ohm
Channel 2	4 mV/div	259.000 mV	1: 1	dc	1M ohm

Trigger Mode: Edge
On the pPositive Edge of Channel2
Trigger Level (s)
Channel1 = 259.000 mV (noise reject OFF)
Holdoff = 40.000 ns

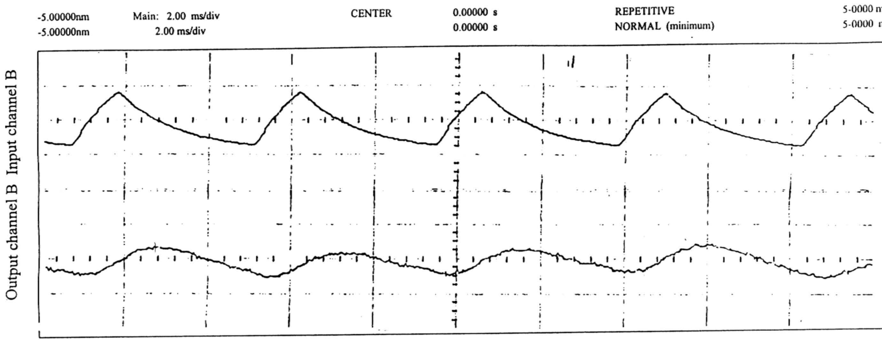
Fig. 4.40 Input output graph of channel A.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	1.00 V/div	962.500 mV	1: 1	dc	1M ohm
Channel 2	10 mV/div	937.500 mV	1: 1	dc	1M ohm

Trigger Mode: Edge
On the pPositive Edge of Channel2
Trigger Level (s)
Channel1 = 270.000 mV (noise reject OFF)
Holdoff = 40.000 ns

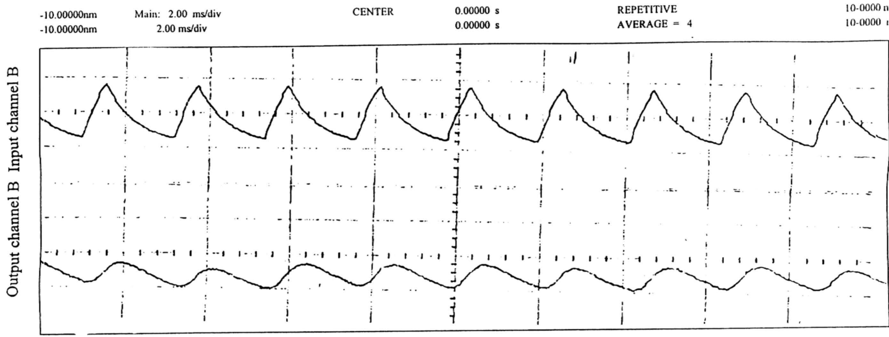
Fig. 4.41 Input output graph of channel A. Out put is mirror image of input due to different postion of slit on the detector.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	1.00 V/div	1.00000 V	1: 1	dc	1M ohm
Channel 2	4.00 mV/div	177.000 mV	1: 1	dc	1M ohm

Trigger Mode: Edge
On the pPositive Edge of Channel21 - when the State [CXX] is present
Holdoff = 40.000 ns

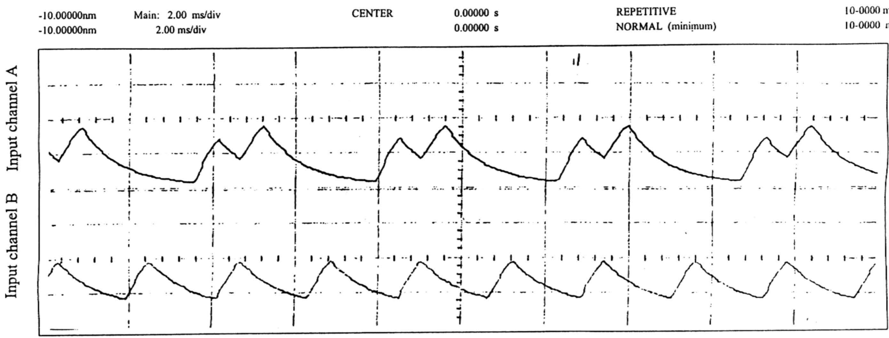
Fig. 6.42 Input output graph of channel B.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	1.00 V/div	1.00000 V	1:1	dc	1M ohm
Channel 2	4.00 mV/div	208.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the pPositive Edge of ChanneР1 - when the State [CXX] is present
Holdoff = 40.000 ns

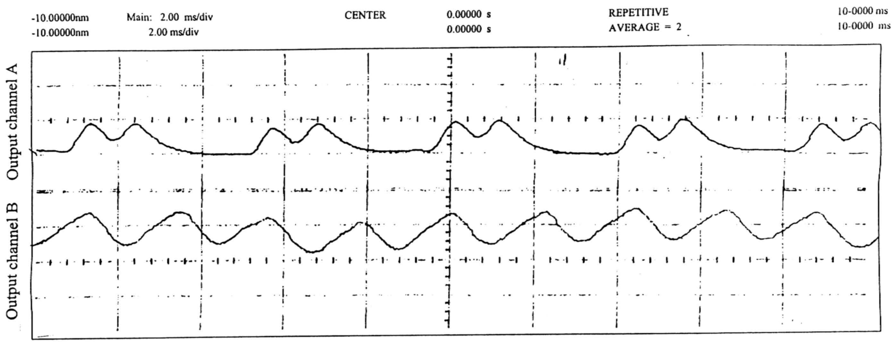
Fig. 6.43 Input output graph of channel B. Output signal is a mirror image of input signal.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	1.00 V/div	2.00000 V	1:1	dc	1M ohm
Channel 2	1.00 V/div	1.50000 V	1:1	dc	1M ohm

Trigger Mode: Pattern
On the Pattern [HXX] - When Range . 20.000 ns and Range , 1.44000us
Trigger Level (s)
Channel1 = 2.00000 V (noise reject OFF)
Holdoff = 40.000 ns

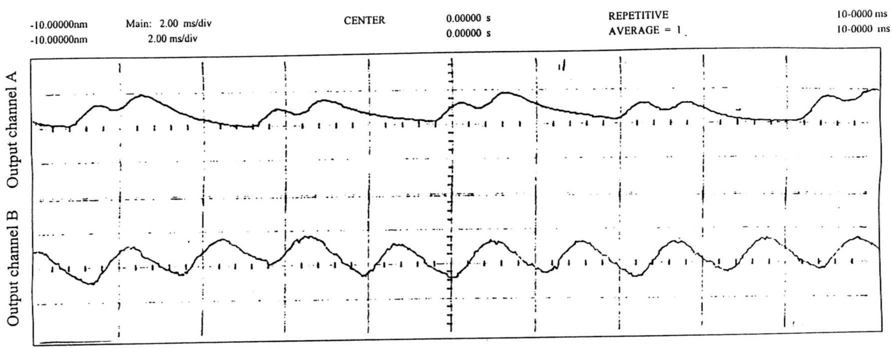
Fig. 6.44 Two input signals for channel A and channel B when both channels are activated simultaneously.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	10.0 mV/div	265.000 mV	1:1	dc	1M ohm
Channel 2	4.00 mV/div	205.000 mV	1:1	dc	1M ohm

Trigger Mode: Edge
On the Positive Edge of External 2
Trigger Level (s)
external = 0.00000 V (noise reject OFF)
Holdoff = 40.000 ns

Fig. 6.45 Output of two signals when channel A and channel B are activated simultaneously.



	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	10.0 mV/div	227.500 mV	1: 1	dc	1M ohm
Channel 2	4.00 mV/div	221.000 mV	1: 1	dc	1M ohm

Trigger Mode: Edge
On the Positive Edge of External 2
Trigger Level (s)
external = 0.00000 V (noise reject OFF)
Holdoff = 40.000 ns

Fig. 6.46 Graph of two simultaneous outputs, channel A and channel B. Output channel B is mirror image of input single B as shown in Fig. 6.44.

6.7 Reference

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