

EXPRIMENT 5

COMPONENTS FOR FIBER COMMUNICATION

OBJECTIVES

In this lab, the components which are needed to build a fiber data distribution system will be explored. Fiber optic components for data distribution are of importance in short-haul applications, such as local area networks (LAN's), which provide information transfer within structures such as office buildings and manufacturing facilities, and in such vehicles as aircraft and ships. These components are also used in longer-haul systems in order to fully utilize the bandwidth of the optical fiber.

This lab will explore two devices, the fused bidirectional coupler and the wavelength division multiplexer (WDM), which are representatives of this larger group. You will get the opportunity to learn about parameters which are common to almost all fiber devices, such as excess loss, splitting ratio, directivity, and crosstalk.

THEORY

L. MULTIMODE BIDIRECTIONAL COUPLERS

The need for devices to combine light from several fibers into a single fiber or to split the light from one fiber into two or more fibers has been recognized ever since optical fibers were first considered as a communications medium. A 2x2 (2 fibers in, 2 fibers out) bi-directional coupler, which is a device for splitting the light in one input fiber into two output fibers, is illustrated schematically in Fig. 5.1. In fiber optic systems they play a role which is equivalent to that of beam splitters in conventional optics or T-taps in electronics. Bidirectional couplers play a critical role in fiber optic instrumentation, high-data-rate LAN's, and communications systems. Star couplers are nxn (n fibers in, n fibers out) devices of the same basic construction.

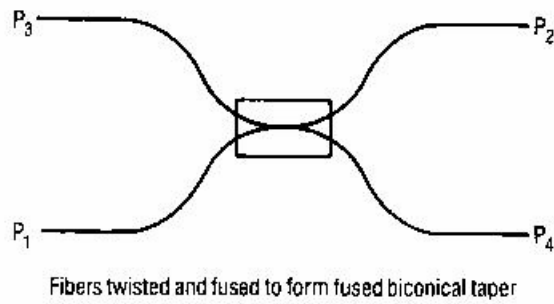


Fig. 5.1 Schematic illustration of the fused biconical taper bidirectional coupler

Bidirectional couplers can be classified into two broad categories, those that use conventional optical beam splitting techniques and those that couple energy between the two fibers using the overlap of the evanescent waves of the light in the cladding of the fibers. Several designs using beam splitting techniques have been developed. These have not found widespread use because of the problem of maintaining the alignment of discrete micro-optic components under extreme conditions. However, this type of device has an advantage over the evanescent wave coupler in that the modal content of the input fiber is preserved in the output fibers.

When the cores of two fibers are close together, the energy is shared between the two overlapping evanescent waves and energy is transferred from one fiber to the other. For this reason, energy coupling between two fibers by this technique is known as evanescent field coupling. The evanescent fields will penetrate significantly into the cladding only for the highest-order rays, i.e., those nearest the critical angle for total internal reflection. Because of this, the coupling obtained using this technique is highly dependent on the modal content of the input fiber. If the light in the input fiber is carried in predominantly higher-order modes, more of the light will be coupled to the second fiber. If the light is in predominantly lower order modes, less light will be coupled. Bidirectional couplers which use this technique actually achieve their specified coupling ratio when light is evenly distributed among the allowed modes of the input fiber.

Light which comes out of Port 2 (using the notation of Fig. 5.1) will be in mostly high-order modes, while the light remaining in the input fiber and coming out of Port 4 will be in mostly low-order modes. This will also have an effect on the performance of any other bidirectional couplers which are now connected in series with the first coupler since the distance between couplers is not likely to be great enough to allow the light to be redistributed among the modes. Couplers downstream from Port 2 will split off more than the specified power, while couplers downstream from Port 4 will split off less than the specified power. This discussion of the modal dependence of the evanescent wave coupling mechanism applies to multimode couplers. Although they are harder to fabricate, single mode couplers are simpler to understand, because they have only a single mode involved in the coupling.

Because of the exponential decay of the evanescent field, the two fiber cores must be brought in close proximity for electric field overlap and optical power coupling to occur effectively. The most commonly employed technique for fabricating the coupler is called the fused biconical taper technique. In this technique, the two fibers are twisted together and then heated to about 1500°C. While the fibers are being heated they are subjected to a tension which causes them to stretch. This stretching increases the coupling between the two cores by two mechanisms. The first is due to the fact that when the fiber is stretched, the fiber cladding is tapered and becomes thinner, causing the two cores to come closer together, thereby increasing the evanescent field overlap. The second comes about because of the thinning of the core itself, which causes a decrease in the V-number of the fiber. This causes the fields' exponentially decreasing evanescent waves to decrease less rapidly as a function of radius, and this also increases the field overlap.

In practice, the stretching is continued until the desired coupling ratio is achieved. When the heating is stopped, the core separation is permanently locked in place. Couplers made by the fused biconical taper technique are extremely insensitive to temperature changes.

The bidirectional coupler which results was shown in Fig. 5.1. Light which is input at Port 1 may either come out of the same fiber at Port 4 or be coupled to the

second fiber and emerge at Port 2. A small amount of light may be returned to the input port of the second fiber, Port 3, because of backscattering and reflections due to the constriction at the taper. The **coupling ratio**, or **splitting ratio**, is defined as the power coupled across to the second fiber divided by the total power through the coupler ($P_2/P_2 + P_4$). Typical coupling ratios for commercially available devices are 3 (50%), 6 (25%), and 10 dB (10%). The **excess loss** is defined as the total output power divided by the total input power ($(P_2 + P_4)/P_1$). Early couplers exhibited losses in the range of 2-3 dB. Most couplers today exhibit losses in the range of 0.5-1.0 dB. The **directivity** of the coupler is defined as the power returned to the input of the second fiber divided by the input power (P_3/P_1). This ratio is typically about -40 dB for good couplers.

In communications applications, the bi-directional coupler is more often used as a tap. Its application is in tapping information off of a main data bus or in inserting information onto the bus.

2. WAVELENGTH DIVISION MULTIPLEXER

The wavelength division multiplexer (WDM) provides the equivalent of multiple transmission lines in a single fiber by sending signals at various wavelengths in the same fiber. The WDM enables an optical fiber to be used more effectively. It allows a greater use of the bandwidth of the fiber, allows bidirectional communications, and allows the simultaneous transmission of different types of signals, such as analog and digital data.

A WDM device consists of two or more input fibers, each carrying a signal at a different wavelength, an output fiber which is connected to the transmission link, and wavelength-selective optical components, such as gratings, prisms, or thin-film filters, for combining the signals at different wavelengths onto the output fiber. A simple two-channel WDM, using two quarter-Pitch graded-index (GRIN)-rod lenses and a wavelength selective filter, is shown in Fig. 5.2a. Signals carried on two different wavelengths, λ_1 and λ_2 , are input from Fibers 1 and 2, respectively. The quarter-Pitch lens collimates the input beam at the point where it sees the filter and the second lens re focuses the beam into the output fiber. The wavelength selective filter reflects λ_1 and

passes λ_2 to be focused at the output, Fiber 3, which is placed symmetrically about the lens axis with respect to Fibers 1 and 2. Demultiplexing of the signals at the receiver is accomplished by simply reversing the path directions. Two-way transmission can be accomplished by replacing one of the sources, for example, Source #2, with a detector, as shown in Fig. 5.2b. The WDM then inserts λ_1 onto the transmission link and receives λ_2 . The WDM at the far end will send λ_2 and receive λ_1 .

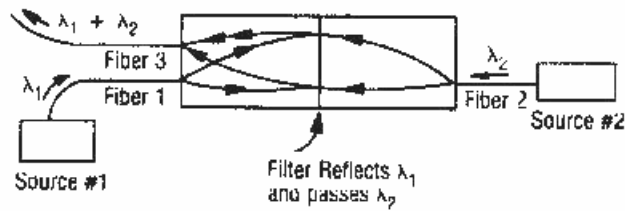


Fig. 5.2a

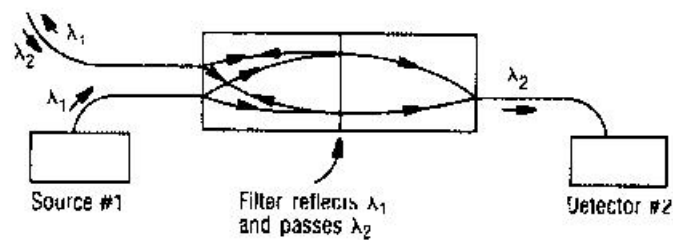


Fig. 5.2b

Fig. 5.2 Interference filter type wavelength division multiplexer (WDM). a) For two-channel transmission. b)

For two-way transmission.

In this lab, we will construct a two-channel WDM of the type described above. The wavelength selective filter is not used in WDM's that have a higher channel count, because an N-Channel WDM would require N-1 filters. This WDM would require the cascading of several filters and this would greatly increase the losses in the device. WDM's of this type generally use a prism or a grating. A design for a five-channel

WDM using a quarter-pitch GRIN-rod lens and a reflective diffraction grating is shown in Fig. 5.3. WDM devices of this type allow more of the total bandwidth of the optical fiber to be used. WDM's employing gratings are now available with more than ten channels.

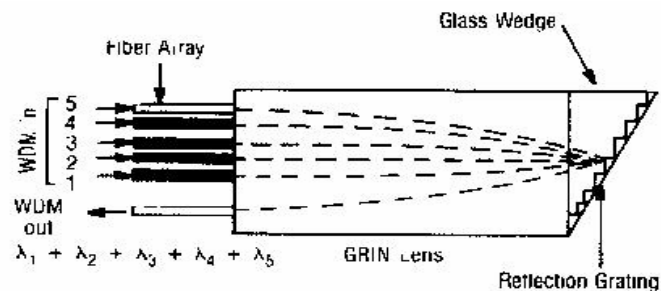


Fig. 5.3 Five-channel grating WDM using a graded-index (GRIN) rod lens.

The two most important parameters in characterizing a WDM are the insertion loss and the crosstalk. If the power to the device from the with source is P_i and the total power form all sources combined on the output fiber is P_T , and then the **insertion loss** is defined as $P_T/\Sigma P_i$. Typical insertion losses are about 12 dB, depending on the type of wavelength selection used, but may be as high as 8-10 dB when LED sources are used in the grating WDM device. The **croostalk**, or **isolation**, is determined after the signals are demultiplexed at the receiver end. The crosstalk from channel i into channel j is defined as the power received from source i divided by the power received from source j when both are measured by the detector for channel j . Typical values for the crosstalk in available multiplexers is generally less then -20 to -30 dB.

PROCEDURE

(1) Bidirectional Coupler

1. Remove a section of the outer jacket from the cabled fiber pigtail of the FK-BTC bidirectional coupler at Port 1. Cleave the end of the fiber. (You can actually use any of the four ports of the coupler, but using Port 1 will allow you to use the notation of the previous discussion.)

2. Splice a one-meter length of F-MLD fiber to the cleaved fiber as you learned to do in LAB #4. This will make it much easier to handle the input to the coupler. However, the splice must be done properly or there may be significant mode coupling at the splice and the following exercise will be meaningless.
3. Couple He-Ne laser light to the fiber at Port #2 as you did in LAB #3. Arrange the input so that low-order modes are preferentially launched into the input fiber. You can check this by visually examining the output from port #4. (Low-order modes will be confined to low output angles. Arrange the launch conditions so that the output cone at Port #4 is as narrow as possible.) Measure the outputs at Ports #2, #3, and #4.
4. Change the launch conditions so that high-order modes are preferentially launched (large output cone). Again, measure the output powers.
5. Return to the launch conditions of Step #3. Use the FM-1 mode scrambler as you did in LAB #3 to generate an approximation of a stable distribution in the launch fiber. Measure the output powers.
6. Pot some index matching fluid such as glycerin on the fiber ends at Ports #2 and #4. Remeasure the returned light at Port #3. Index matching will reduce the light returned to Port #3 by Fresnel reflections from the far end of the fiber at Port #2 and #4.
7. Compare the results of Steps #3-#6. What conditions are assumed when the manufacturer quotes a 3 dB splitting ratio and a directivity of --40 dB?

(2) Wavelength Division Multiplexer

1. Prepare four lengths of F-MLD fiber, each about 1 to 1.5 meters long as you did in LAB #3. Construct an array of two fibers as follow: Lay two lengths in a single FPH-S fiber chuck (Fig.5.4a) so that they are parallel and so that the fiber end faces are co-planar (Fig. 5.4b). Mix some of the two-part epoxy (F-TK1E) and place a drop at both ends of the fiber chuck (Fig. 5.4c). Make sure that the epoxy does not run over the end faces of the fibers or over edge of the chuck, because this chuck will have to be inserted into an FP-1 fiber positioner. Allow the epoxy to fully cure.

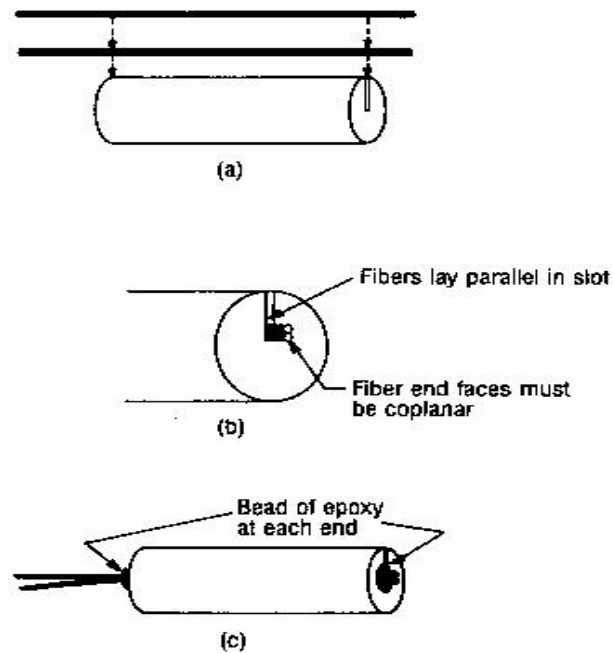


Fig. 5.4 Construction of a two-fiber array. (a) Lay two cleaved fibers in an FPH-S Fiber Chuck. (b) Fibers must lay parallel in the chuck with co-planar end faces. (c) Apply a bead of epoxy at each end to hold fibers in place. Do not allow epoxy to run over the edge of the chuck or over the end faces of the fibers.

2. Repeat Step 1 with the other two lengths of fiber and a second FPH-S chuck.
3. Assemble the lenses for the WDM device. We need two of the GRIN-rod lenses as shown in Fig. 5.5a. One is coated with an interference filter which passes the light from the ILD and reflects the light from the LED (Model No. FK-GR25F). The other does not have this interference filter (Model No. FK-GR25P). Both are coated on one end with an anti-reflection coating. Place one of each of these lenses on an FK-MUX Multiplexer Assembly Base, with the anti-reflection coated end (marked with a small black dot) toward the outside of the assembly base as in Fig. 5.5b. Epoxy these in place, making sure that there is a film of epoxy between the two lenses for index matching purposes.

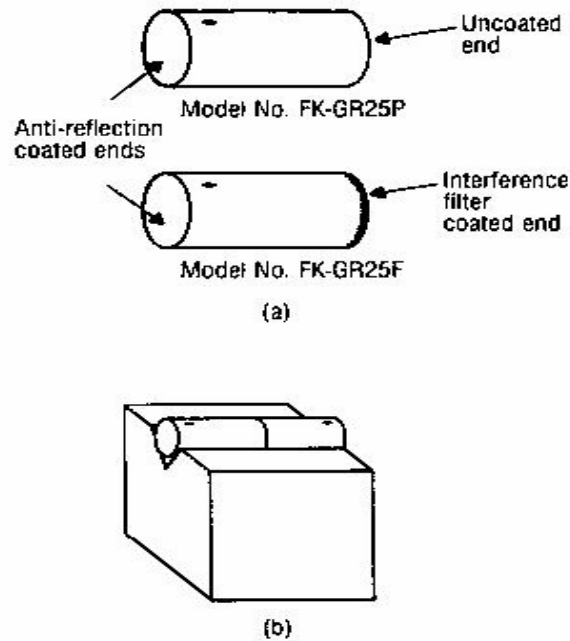


Fig. 5.5 (a) GRIN-rod lenses used in the assembly of the WDM device. (b) Assembly of the GRIN-rod lenses on the FK-MUX multiplexer Assembly Base

4. The procedure listed in Step #3 for assembling the lenses of the WDM was quite involved. However, you now need to repeat the procedure of Step #3 in order to assemble the lenses for the wavelength demultiplexer device.
5. Prepare another 1 to 1.5 meter length of F-MLD fiber and couple the output of the ILD into it as you did in LAB #3. The precautions noted there still apply here. This fiber will be fiber #2 of Fig. 5.2a. Use the 815 Power Meter to measure the amount of power coupled into this fiber.
6. Couple the light from the LED into one of the fibers which you have epoxied into one of the FPH-S Fiber Chucks as you did in LAB #3. This fiber will be fiber #1 of Fig. 5.2. Use the 815 power-meter to measure the amount of power coupled into fiber #1. The other fiber in the same chuck will be fiber #3.
7. Post-mount one of the WDM assembly bases with the lenses epoxied in place. Use the SP-3 Post so that the lenses can be aligned at the proper height with respect to the fibers in the FP-1 Fiber Positioner. Place the chuck with fibers #1 and #3 in a post-mounted FP-1 Fiber Positioner.
8. Couple light from fiber #1 to fiber #3 by aligning the fibers with the lenses as shown

schematically in Fig. 5.6. When the two fibers are located symmetrically about the center line of the lens, LED light from fiber #1 will be reflected from the interference filter, which is now located between the two GRIN-rod lenses, and will be focused into fiber #3.

9. Place fiber #3 in an FPH-S Fiber Chuck. Hold this chuck in an MPC Collar and post-mount the assembly. Position the 815 Power Meter so that you can measure the coupled power.

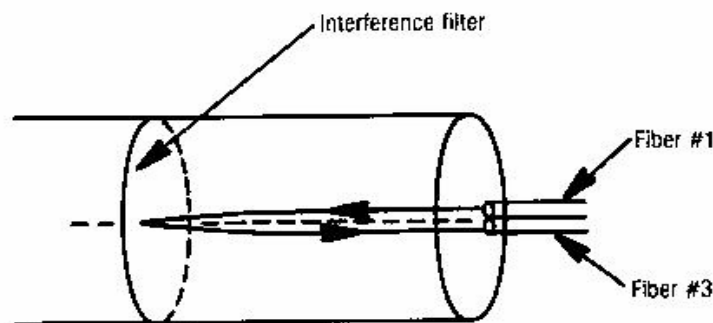


Fig. 5.6 Coupling light from Fiber #1 to Fiber #3. When the fibers are placed symmetrically about the center line of the lens, light out of Fiber #1 will be reflected by the interference filter and be focused into the core of Fiber #3.

10. Measure the power in fiber #3 and calculate the insertion loss of the WDM for this channel.
11. Once Step 10 is completed, place the fiber into which you have coupled light from the ILD in an FPH-S chuck and place this in an FP-1 Fiber Positioner. Post-mount this FP-1, completing the arrangement of equipment.
12. Couple light from fiber #2 into fiber #3 as shown in Fig. 5.7. Adjust fiber #2 until the maximum coupling is achieved. Fiber #2 will be symmetrically across the lens center line from fiber #3 at the opposite end of the lens assembly. Do not move the position of fiber #3, as this will reduce the coupling from fiber #1 into fiber #3. Measure the ILD power coupled into fiber #3 and calculate the insertion loss for this channel.

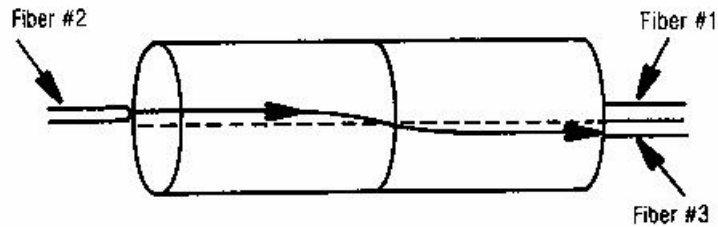


Fig. 5.7 Coupling light from Fiber #2 to Fiber #3. Fiber #2 is placed symmetrically across the center line of the lens from Fiber #3 at the opposite end of the lens assembly

13. Using one of the splices which you used in LAB #3, dry splice (no epoxy) fiber #3 to one of the fibers which have been epoxied into the other FPH-S chuck. Measure the optical power for each channel coupled through the splice.
14. Repeat Steps 7 and 8 for this end of the link. You are now putting together the demultiplexer, so fiber #3 is the input, with channels 1 and 2, and fiber #1 is the output (the arrows indicating the light path are reversed in Fig. 7.6). Measure the LED power in fiber #1 and calculate the insertion loss of the demultiplexer for this channel.
15. Repeat Step 11 for the demultiplexer. The fibers with the demultiplexed signals may be placed in the remaining FPH-S Fiber Chucks. Hold these in two post-mounted MPC Collars to couple to the 815 Power Meter. Measure the ILD power in fiber #2 and calculate the demultiplexer loss for this channel. The arrows indicating the light path are reversed in Fig.5.7 for the demultiplexer.
16. Measure the ILD power in fiber #1 and the LED power in fiber #2. Calculate the crosstalk in each channel using the definition given in the theory.

Question:

1. Please give the definitions and meanings of coupling ratio, excess loss, and directivity of the coupler by virtue of the Fig. 5.1.

2. Please give the definitions and meanings of insertion loss and crosstalk in WDM.
3. What do you think about the nature of the wavelength division multiplexing? By which kind of main components did you use to implement the WDM in the lab?