Comparative research on plastic optical fiber joined type optical couplers

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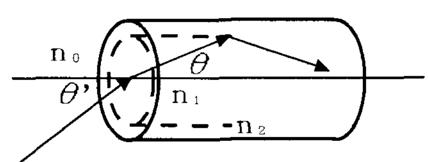
Introduction

Recently high speed communications using plastic optical fiber (POF) have become possible. Optical fiber has become necessary that may be used in high speed communications networks with broad band POF. Optical couplers for usual POF have already been proposed.[1] For branching, they use the optical signals passing between the joined POF, extracting a portion of these signals. The major difference between usual POF and broad band POF is their NA. While the former have 0.5 NA and a transmission angle inside the fiber of 20 degrees, the latter have 0.3 NA and a transmission angle inside the fiber of 11.7 degrees. It has been reported that if optical couplers are produced by POF with low NA, there are few opportunities for optical signals in the joined portions of the POF to move to the branching side from principal side and that it is difficult to obtain equal distribution.[2] This report observes the transmission angles of optical signals and compares the fusion designs of optical fibers and the conditions of signal distribution.

1. Optical signals transmitting along POF

POF are made up of a core, which takes up the greater part of the cross-section, and a clad layer, which provides a thin cover around the core. The numerical aperture(NA) is calculated with Formula in Figure 1 from the core's refractive index and the clad's refractive index. Optical signals travel along the inside of POF refracting and reflecting according to Snell's Law. Therefore, the larger the NA the easier it becomes to introduce the optical power of a light source into POF. However, since the distance travelled inside POF is great, the insertion loss value is large. For example, heat resistant POF with large differences in refractive index between core and clad have high NA of 0.55 and transmission losses of 500dB/km. POF designed for communications purposes have NA of 0.47 and transmission losses of 250dB/km. And, the transmission band narrows as the optical path differential grows, they are not suited to high speed optical communications. The GI-POF (gradient refractive index plastic optical fiber) recently developed and the special low NA SI-POF (step refractive index plastic optical fiber) that may be used for high speed optical communications have low NA of 0.3.[3][4] Optical signals travelling along the inside of these optical fibers have transmission angles of 11.7 degrees and less.

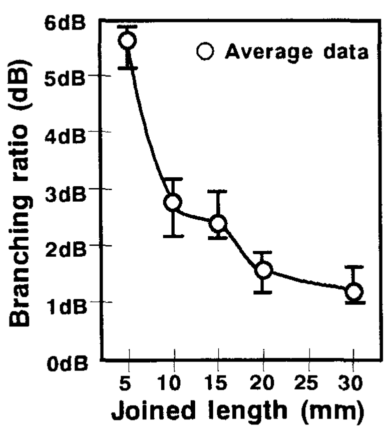
Figure 1: NA and Snell's Law



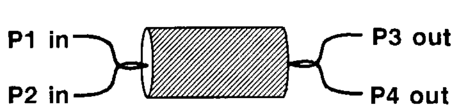
$$NA = n_0 \sin\theta' = n_1 \sin\theta = (n_1^2 - n_2^2)^{1/2}$$

2. Performance of POF Joined couplers

POF junction type optical couplers in our reports have structures in which some of the POF are simply joined in parallel. Therefore, the optical signals cross between the POF with the joined surfaces as their boundaries and with almost no change in the transmission angles of the optical signals travelling along them. Branching performance depends on the frequency of those comings and goings of optical signals. This structure has the following two advantages: The original clad layer exists on the flanks of those POF not joined, and they obstruct the leakage of overloaded optical signals. By maintaining transmission angle, they broad band for transmission. However, the volume of optical signals crossing between the POF affects branching performance, it is necessary to control the surface area joined. An optical coupler with ultra sonic fusion over 20mm of its POF, which are 1mm in clad diameter, has the characteristics shown in Table 1. We used a method of ray tracing to compare the relationship between the junction design of POF and their branching performance. Graph 1 shows the relationship between the joined length of the POF and the branching performance of optical signals. From the graph we found that although the rate of distribution gets smaller as the joined length gets longer, it does not reach a 1:1 ratio. The results of reliability tests showed that the joined portions of the POF couplers are stable and heat and humidity have about the same effects as on POF.[1]



Graph 1: Relationship between joined length and branching ratio compression rate is 10%



Branching ratio = 10 ×log | P3/ P4 |

Table 1. Loss table of 2X2 coupler

	Output		
Input	3ch	4ch	Excess loss
1ch	3.3dB	4.0dB	0.6dB
2ch	4.1dB	3.2dB	0.7dB

* Usual POF(NA=0.5) joined coupler
** Stabilized light source LED (670nm)

3. Change in transmission angle

Inside optical couplers with POF junction type, optical signals come and go, the joined sections acting as windows. The comings and goings of optical signals depends on the transmission angle. Thus we conducted an experiment of joining POF that had been slightly curved rather than the parallel junction of POF design used heretofore. Figure 2 shows the curved design and a conceptual diagram of signal transmission. Optical couplers made by compressing a 20mm joined length with a large arc with a radius of 200mm when performing ultrasonic fusion had a smaller rate of distribution. Optical couplers made with standard POF with NA of 0.5 had a distribution rate of 1:1.2.[5] The rate of distribution decreased, therefore, it was possible to form an optical star coupler linking several optical couplers. Table 2 gives the optical characteristics of the optical star coupler. Measuring transmission band with the pulse method, we obtained a value of 10GHz per POF junction. This means that the angles of few optical signals change in the curved sections of the POF, the differences in optical paths generated in the joined sections in exceedingly small.

Figure 2: Diagram of the curved junction design

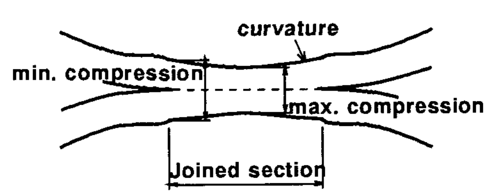


Table 2. Loss table of 4X4 star coupler

	Output			
Input	5ch	6ch	7ch	8ch
1ch	6.6dB	7.5dB	7.7dB	8.2dB
2ch	7.6dB	8.3dB	6.5dB	7.5dB
3ch	7.4dB	6.5dB	8.2dB	7.5dB
4ch	8.2dB	7.6dB	7.6dB	6.5dB

* Usual POF(NA=0.5) joined coupler
** Stabilized light source LED (670nm)

4. Prototypes of broad band couplers

The performance of POF joined type optical couplers depends on the volume of optical signals crossing between the POF. Therefore, it is difficult to branch optical signals with small transmission angles efficiently. Thus, we essayed a method of temporarily converting optical signals with small transmission angles to large angles and returning them once again to their original transmission angles after branching. Transmission angles may be changed by tapering the shape of the POF in the direction of propagation. When returning to the original transmission angles, the shape of the POF tapers in reverse. Figure 3 shows the change in transmission angles. At this time the diameter of the POF route partially thin, and light travels along those sections at larger angles than previously. The light branching happens in these sections. However, it is necessary to note that between the core and clad of the POF used in these couplers the refraction differentials are restricted to the light originally transmitted. We made the tapered POF routes by heating and stretching sections of POF with small NA. We then applied ultrasonic fusion to the stretched sections to produce optical couplers. The resulting optical couplers with joined broad band POF obtained the optical performances showed in Table 3. In particular, the sample in which signals were branched after coercing the transmission angle to 20 degrees (corresponding to POF of NA=0.5) demonstrated about the same optical performances optical couplers produced in the traditional junction with standard POF.

Figure 3: Diagram of the broad band coupler

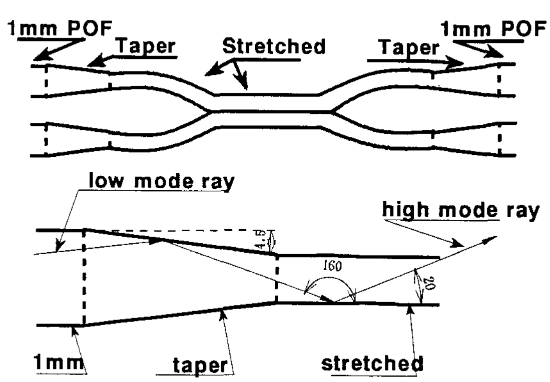


Table 3. Loss table of broad band coupler

	Output		
Input	3ch	4ch	Excess loss
1ch	3.7dB	5.5dB	1.5dB
2ch	5.5dB	3.6dB	1.5dB

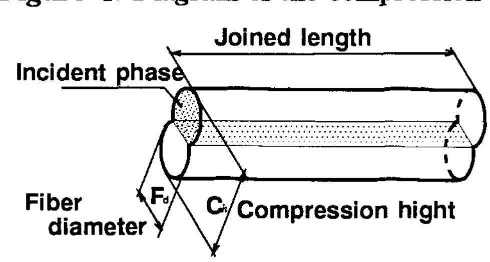
* Usual POF(NA=0.3) joined coupler

** Stabilized light source LED (670nm) and launching NA is 0.2.

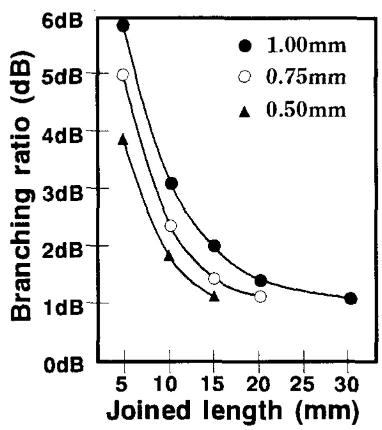
5. Optical characteristics of couplers

In the POF, there is a type with different several thickness, depending on their usage. Those used for communications are 500 μ m, 750 μ m and 1,000 μ m clad diameter. The distribution characteristics that vary with POF diameter are estimated with optical calculations as shown in Graph 2. The compression design of POFs has the primary influence on insertion loss and excess loss. Compression design is defined in Figure 4. When performing ultrasonic fusion, the POF are pressurized. The compression rate is controlled through modulation of this pressure. Our experiments showed that crimping of about 10% is to be desired. Under 10%, the surface area of POF junction decreases and it is difficult to branch optical signals. Over 10%, gradations develop between the original POF and the joined sections and optical signals scatter. Graph 3 shows the relationship between compression rate, branching ratio and excess loss. Since the joined sections are extremely short in POF junction type optical couplers, either design demonstrated broad band. Measuring optical star couplers linking joined sections serially with the same method, we obtained values 2GHz lower per joined section.

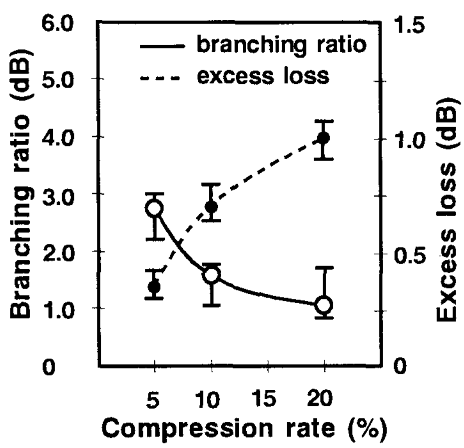
Figure 4: Diagram of the compression design



Compression rate=(2 · Fd − Ch) / 2 · Fd



Graph 2: Relationship between joined length and branching ratio compression rate is 10%



Graph 3: Relation between branching ratio and compression rate numericai aperture is 0.5.

Summary

Multi-mode light travelling along POF is transmitted reflecting repeatedly between the core and clad surface boundaries. The comings and goings of optical signals occurs at the windows where POF cores are sectionally joined. The comings and goings of optical signals depends on the transmission angle with which they travel the inside of the POF; the larger that angle, the more opportunities they have to traverse between the POFs. This is intimately related to the capacity for distribution of optical signals.
POF on the market may be classified according to that characteristic as for industrial, communications or automobile use. Since polymers are used as bare fiber as appropriate to those usages, their NA and particular loss values are, of course, different. In optical communications networks it is difficult to determine the description of POF used for extension, and it is not unusual for several POF to be mixed together and connected on the way. The optical link units used in such environments will not deliver the intended performance unless the insertion environment is given careful consideration. In the standardization of POF optical couplers, NA must also be considered.

References

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