Compact Monitor device for Multicore Fibre with Practically Low loss using Multiple Lenses

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Abstract We present two monitor devices using multi-core fibre. Both are built with 1 dB or less loss. One of them is a device with Fan-Out function and the other is a photo detector for multi-core application. Key technology is a new structure using multiple lenses.

Introduction

In recent years, the demand for network services such as web conferencing and video distribution has expanded communication traffic rapidly, and various researches on space division multiplexing (SDM) have been conducted to address them.[1] These studies are already in the phase of practical application level.[2] Especially in multi-core fibres (MCF), studies have been conducted with emphasis on fibre manufacturing and compatibility with existing equipment by making the cladding diameter 125 μm the same as existing single mode fibres (SMF).[3] Transmission loss reduction[4] and optical amplifier[5] are examples of research using such MCF. With this shift, SMF devices for a telecommunication network must also be updated for MCF. If the existing SMF device is used as it is, it is necessary to once branch the propagated light in the MCF into a single mode fibre (SMF) by a Fan-In / Fan-Out (FI/FO) device.[6][7] This is a great disadvantage in terms of transmission loss and space. Until now, various MCF devices have been researched, but they are much higher than 1 dB and there was no usefull one.[8] Furthermore, in the MCF optical amplifier research, there was no practical device for monitoring even though efforts were made to make the light intensity of each core equal.[9]

As one of the solutions, in our recent research, we have developed a tap isolator fibre module for 5-core MCF with a cladding diameter of 125 μm.[10] By using 2-MCF array technology, this module has a very low loss (0.74dB), showing that it is a compact module with sufficient performance for practical use.

Furthermore we needed to add functionality to this device to improve usability. However, it has been difficult to obtain sufficient characteristics with a simple two-lens combination structure that has been used in conventional MCF devices.

In order to solve this problem, we devised a new device structure using multiple lenses that has not been used in MCF devices, and actually developed two devices. In this paper, we demonstrate the utility of this design method and show that the actually manufactured device has sufficient performance for practical use.

New device structure using multiple lenses

We describe the unique restrictions when designing with spatial optics for MCF device. Fig.1 shows a schematic of the basic optical layout of an MCF device with two lenses. When designing a module for spatial optics using MCF is the use of telecentric imaging optics method. It is necessary to match the focal length of the lens to be used with the arrangement of the optical elements. This is a unique restriction of the MCF where the core is placed other than the centre of the lens.

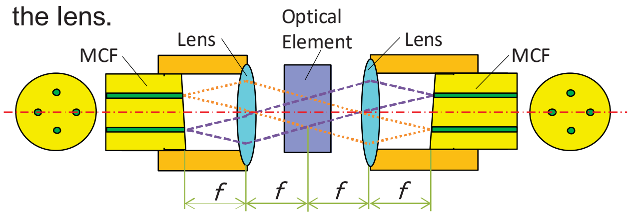

Fig. 1: Schematic of basic optical layout of MCF device

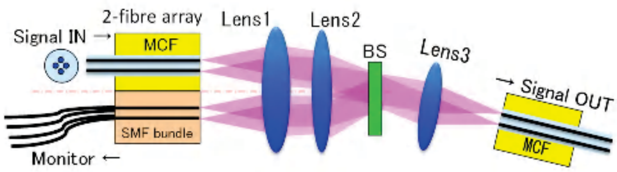

Fig. 2: Schematic of monitor device with FO (NEW)

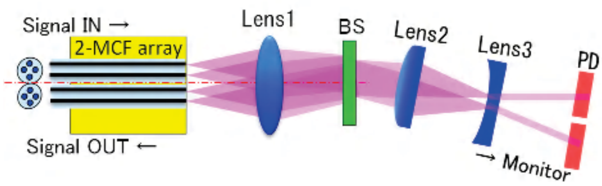

Fig. 3: Schematic of monitor device with PD (NEW)

Next, the features of the new device structure will be described. Fig.2 shows a schematic of the monitor device with Fan-Out (FO), and Fig.3 shows a schematic diagram of the monitor device with photo diode (PD). These are newly-developed devices, and have adopted an unprecedented new structure using multiple lenses while retaining the structural restrictions peculiar to MCF. Furthermore, they are in the form of practical 3-port devices using the recent trend of Φ125 μm clad diameter 4-core MCF.

However, these two devices have adopted multiple lenses structures for different purposes. The former is used to reduce off-axis aberrations, and the latter is used to obtain an appropriate spot size and dispersion angle for each core. These are characteristics that could not be obtained with the existing two-lens configuration.

Fabrication of monitor device with FO

Fig.4 shows the schematic of the structure of Fan-out built in monitor devices. This module consists of an 2-fibre array of SMF bundle and MCF, three single lenses, a beam splitter(BS), and an output MCF. BS used at this time had a branching ratio of 96.4% on the transmitting side. A major feature is that it uses the two-fibre array technology that contributes to device miniaturization. This device uses the SMF bundle that is made by bundling the SMF to a core pitch of the MCF in order to add the Fan-OUT function to the TAP monitor side. In the conventional 2-MCF array, each fiber was fixed adjacent to one ferrule. On the other hand, this time, both the MCF and SMF bundle had to be fixed to independent ferrules. As a result, the distance between the MCF and SMF bundles is 1.8 mm, which is much wider than before. In general, light away from the centre of the lens is susceptible to aberrations and increases coupling loss. Since there were similar concerns this time as well, we conducted an optical simulation to verify.

Fig.5 shows the schematic of the optical layout and spot diagram during simulation. First, in the simulation, the beam spot diagram on BS was elliptical. This effect is from off-axis aberrations. Furthermore, the coupling efficiency in that state was 0.66 dB. In this simulation, transmission loss and other factors were not included, and it was expected that the loss would actually worsen. So it was clear that this configuration was not practical. In order to reduce the effect of this aberration, measures were taken to reduce the refraction angle per lens surface by using multiple lenses in this device. This method is a general method for reducing aberrations in imaging optical systems used in cameras. A good characteristic of 0.05 dB was obtained by the evaluation of the coupling loss In simulation of this method.

As the optical arrangement, first, the input side MCF and the SMF bundle are arranged so as to have the same distance from the lens centre. By arranging the BS at the composite focal position on the front side by the two lenses on the input side, the coupling relationship in the reflected light between the input side MCF and the SMF bundle is constructed. The composite focal length at this time is expressed as:

$$\frac{1}{f} = \frac{1}{f1} + \frac{1}{f2} - \frac{d}{f1 \times f2} \qquad (1)$$

In this equation, f represents the composite focal length, f1 and f2 are the focal lengths of the lens 1 and the lens 2, respectively, and d represents the distance between the lens 1 and the lens 2. The light transmitted through the BS is optically coupled to the MCF on the output side by one lens equivalent to the composite focal length of the two lenses on the input side described above.

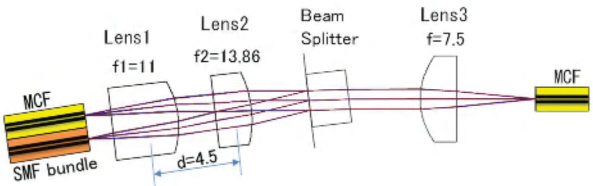

Fig. 4: Schematic of structure of Fan-out built in monitor device

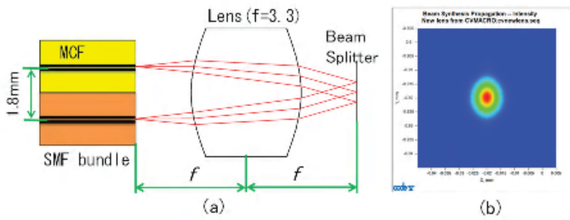

Fig. 5: (a) optical layout of simulation (b) Beam spot diagram on BS

Fabrication of monitor device with PD

Fig.6 shows the schematic of the structure of PD built in monitor device. This module consists of an 2-MCF array, three single lenses, a beam splitter(BS), and a 4-part PD. BS used at this time had a branching ratio of 1% on the transmitting side. Since this device has a structure in which two MCFs are fixed adjacent to one ferrule, the distance from the centre of the lens can be reduced. For this reason, the lens on the incident side is used as a single.

The BS is placed at the front focus position of the input side lens. In this module, the light reflected by the BS is used as the signal light output, and the light transmitted through the BS is received by the PD as the monitor light. The light transmitted through the BS is introduced into the PD. Its light receiving section is divided into four. In accordance with this, it is necessary to separate the light from the core. Further, it is necessary that the spot size is appropriate for the size of the light receiving section. For example, if the f1.8 mm lens is used alone to separate the beam from the MCF and let it be received by the

PD, the separation angle is 1.28 deg, so the optical path length must be at least 45 mm or more. Also, since the beam size at that time is about 360 μm, it can receive light because the PD's light receiving size is φ500 μm, though a smaller beam size is preferable. In order to improve these, the lens on the output side uses a two-element configuration that combines a convex lens and a concave lens. As a result of this, the separation angle was 3.4 deg, the optical path length could be shortened to about 33 mm, and the spot size was φ160 μm, which was sufficiently smaller than the light receiving size. In addition, the incident angle of light on the PD is designed to be tilted outward rather than vertical. The purpose is to prevent the reflected light from the PD from returning to the original optical path and deteriorating the return loss.

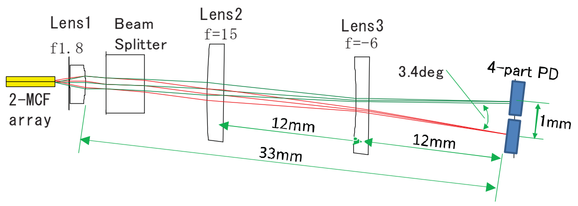

Fig. 6: Schematic of structure of monitor device with PD

Characteristics of monitor device with FO

Fig.7 shows an external view of the prototype monitor device with FO, and Table 1 shows the insertion loss (IL) characteristics. The size was W15mm x H12.5mm x L50mm, and it was realized in a compact size while incorporating the Fan-Out function. The average insertion loss at the signal port was 0.57 dB and the 3σ value was 0.20 dB. The average insertion loss at the monitor port was 15.79 dB, and the 3σ value was 0.39 dB. In this way, good characteristics with low loss and little variation were obtained.

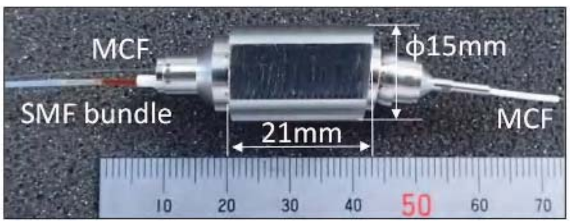

Fig. 7: Photograph of monitor device with FO

Table1 : Insertion Loss of monitor device with FO (in dB)

	CH No.				Ave	3σ
	1	2	3	4		
Sig IN→ Sig.OUT	0.51	0.66	0.56	0.53	0.57	0.20
Sig IN→ Mon.OUT	15.69	15.98	15.74	15.74	15.79	0.39

Characteristics of monitor device with PD

Fig.8 shows an external view of the prototype monitor device with PD, and Table 2 shows the insertion loss (IL) characteristics. The size was φ12mm x L50mm, and it was realized in a compact size. The average insertion loss at the signal port was 0.55 dB and the 3σ value was 0.71 dB. The average insertion loss at the monitor port was 20.76 dB, and the 3σ value was 0.94 dB. Although the loss value was low, it remained to be improved because the loss varied widely.

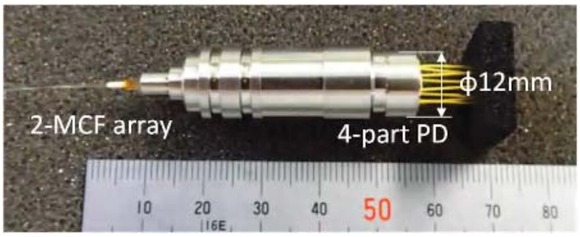

Fig. 8: Photograph of monitor device with PD

Table2 : Insertion Loss of monitor device with PD (in dB)

	CH No.				Ave	3σ
	1	2	3	4		
Sig IN→ Sig.OUT	0.27	0.54	0.85	0.54	0.55	0.71
Sig IN→ PD.OUT	20.64	21.20	20.72	20.47	20.76	0.94

Conclusions

We have successfully realized a monitor device with FO and a monitor device with PD. The two devices adopted the 2-fiber array technology that contributes to miniaturization, and the loss characteristics of the signal light of both modules are well below 1 dB, and good characteristics were obtained. These have been realized using a new device structure that uses multiple lenses. These characteristics are difficult to obtain with the conventional configuration using only the existing two-lens configuration in the MCF device. We would like to contribute to the practical application of systems and networks using MCF by using such technology.

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