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High resolution tunable POF multimode power splitter

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ABSTRACT

A 1 × 2 optical polymer waveguide splitter of dynamic power tuning capability with low excess loss and high tuning resolution is presented. The device was developed based on angular misalignment technique of plastic optical fiber (POF) by allowing predetermined power to split out asymmetrically to two output ports. Non-sequential ray-tracing simulation and mathematical expression of the waveguide outputs matched well to the measured data. Excess loss of the dynamically tunable power-splitter maintains in the range of 0.58–1.85 dB, while the measured splitting-ratio resolution between adjacent power-tuning points is ±0.5% for both output ports. This dynamic power-tuning device would lead to some practical applications such as monitoring, power-controlling applications and sensor.

1. Introduction

Development of very large-scale passive integrated optical circuits for short distance network provides avenues for a scalable dynamic power splitting component to be deployed. Most multimode POF power splitters in the market are found to be of the fixed branching ratios. And more often than not, these branching ratios would differ slightly from the original set values due to deficiencies in the splitter designs and fabrication tolerance, where dimensional variation is inherent in the process [1–5]. For the optical couplers to be mass produced with all the different branching-ratios, it will be a time consuming effort and will not be cost effective [6]. With rapid development in integrated optical devices, it is crucial for a device to have accurate splitting ratios (SR) for specific applications [7]. Thus, optical power splitters that can be tuned to a required SR are highly demanded.

Tunable optical splitter based on single-mode silica fiber waveguide structure is also on high demand, particularly for long haul communication network systems and it is rigorously studied [8–14]. Single-mode structure requires more expensive equipment for fabrication and testing, and is to be handled with extra care due to its microscale structures. Short-range communication system usually employs multimode POF as the signal carrier for the communication links as it has added advantage over single-mode silica fiber in terms of ease in handling, and lower cost for manufacturing and installation. Communication systems consist of not only the optical fiber, but it comprised of many other optical components, and multimode optical couplers among these components. Tunable optical power-splitter is essential in the deployment of integrated optical devices. Excess loss has been the concern of such device, besides imprecise tuning accuracy and low splitting-ratio resolution. These have prompted and motivate the study on POF tunable splitter [15,16]. By employing tunable splitter based on POF, transmitting signals can conveniently be assigned to any desired power splitting-ratios for specific and useful cost-effective applications.

The first variable-ratio optical junction device was patented in late 1970s [17]. The device output was adjusted relative to the end face of the input fiber in order to obtain a range of asymmetrical power ratios. The variable SR can also be varied by tapping bus fiber towards a straight fiber [18]. Collected cladding mode at the high refractive junction is transferred to the tap fiber. Another technique describes the variable SRs can be accomplished by moving two adjoining output fibers by lateral displacement [19]. These variable splitters are limited to ~10.0%–90.0% (±10%) SRs with high insertion and excess loss. The reported 3-dB POF splitters have the lowest excess and insertion loss of 0.7 dB [20] and 4.1 dB [1] respectively utilizing laser light source.

POF devices has been recognized in-car electrical devices connections owing of its light weight, immunity to electromagnetic interference, high security and high-bandwidth. The devices have been successfully implemented in vehicles introduced by Media Oriented Systems Transport, also known as MOST [21]. In a test, MOST was using 10:90 POF Y-splitter to reduce a bulk plugging for vehicle infotainment system [22]. Due to high attenuation of the Y-splitter, the test failed. Thus an attenuator was designed by adjusting the distance, $s < d$

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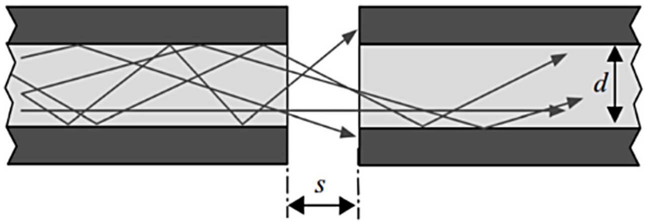

Fig. 1. Concept of power attenuation by MOST [22].

between transmitter fiber and receiver fiber to obtain the required attenuation range, as shown in Fig. 1, where s is the distance between the fiber end facets and d is the fiber core diameter.

By using similar concept, we demonstrate a low loss tunable power-splitter with high tuning resolution by employing angular misalignment method within a hollow waveguide Y-junction. The fiber end of the input-POF at the junction of the hollow waveguide was made to deflect light at 5-μm step-movement across the fiber ends of two receiving output-POFs. Based on ray tracing simulations and experimental design of the splitter, it was found that this technique could realize a wide range of SRs from 1% to 99% with tuning resolution of 1%. Lower excess and insertion loss were achieved using coherent light source from laser as compared to spontaneous light emission from LED. The novelty of the present work is the device achieves variable SR with superior resolution of 0.5 μm with 0.1% power variation. Simultaneously, Y-shape splitter with a branching angle is used to allow space one another. Hence, the light can be coupled out easier, without interference between output port 1 and output port 2.

2. Device design

The asymmetric SRs were realized by using the concept of power transmission at angular misalignment. Previous literatures have details on the power coupling between two SI-multimode fibers with angular misalignment [23–25]. Since the extrapolated design involve three fibers, the effective cross-sectional area A_2 and A_3 of these fibers can be varied depending on input fiber deflection with misalignment difference Δx. Leaky modes have not been considered in calculating the power coupling in these areas. Fig. 2 demonstrates the design of misalignment fiber power transmission of the tunable splitter structure.

The transmitted power from Fiber-1 to Fiber-2 and Fiber-3 are calculated based on the overlapping cross-sectional area of the fiber end-faces. The total power within Fiber-2 (P_2) can be estimated by calculating the total overlap area between Fiber-1 (A_{21}) and Fiber-2 (A_{22}) as shown in Fig. 3(a). Segment A_{21} can be determined by deducting the area of the triangle from the sector as shown in Fig. 3(b). It can be expressed as:

$$A_{21} = 2r^2\cos^{-1}\frac{d}{2r} - \frac{d}{2}\sqrt{4r^2 - d^2}. \quad (1)$$

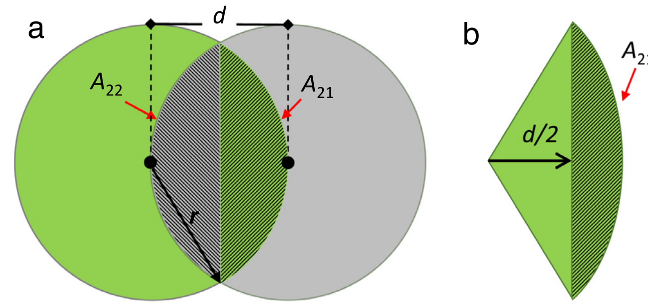

Fig. 3. (a) Overlap area between two identical fibers can be obtained from the sector calculation, (b) showing one of the overlap sector A_{21}.

Where d is defined as the length of the overlapped area between the two centers of the POFs, $d/2$ is defined as the half of the overlapped area between the two centers of the POFs, and r is the radius of the POF. The power transmitted within Fiber-2 can be written as:

$$P_2 = (A_{21} + A_{22})I \quad (2)$$

where I is radiance of light source. Similarly, the transmitted power within Fiber-3, P_3 can be measured for the overlap area 1 (A_{31}) and 3 (A_{33}). Thus,

$$P_3 = (A_{31} + A_{33})I. \quad (3)$$

From these equations, the insertion and excess losses can be estimated. It can be written based on transmitted power obtained from Eqs. (2) and (3).

$$\text{Insertion} \quad \text{Loss} = -10\log\left(\frac{P_i}{P_1}\right) \quad (4)$$

where i can be either 2 or 3 and P_1 is the input power. Hence, the excess loss is given as,

$$\text{Excess} \quad \text{Loss} = -10\log\left(\frac{P_2 + P_3}{P_1}\right). \quad (5)$$

Generally, the SR can be expressed as,

$$SR_i(\%) = \left(\frac{P_i}{P_2 + P_3}\right) \times 100\%. \quad (6)$$

The schematic design of the proposed tunable power-splitter is shown in Fig. 4, where both of the output fibers are redirected away from each other from the junction. Kim et al. [20] has reported that POF transition region from circular to rectangular core with specific length can reduce the loss substantially. There is no leakage between the cylindrical fiber and the rectangular mold insert. With regard to the fabrication of this device, the rectangular POF with specific length of the transition region is improbable. For this reason, the output fibers at the junction were extended by 3 mm to join both output fibers together. So that the loss at the junction can be avoided.

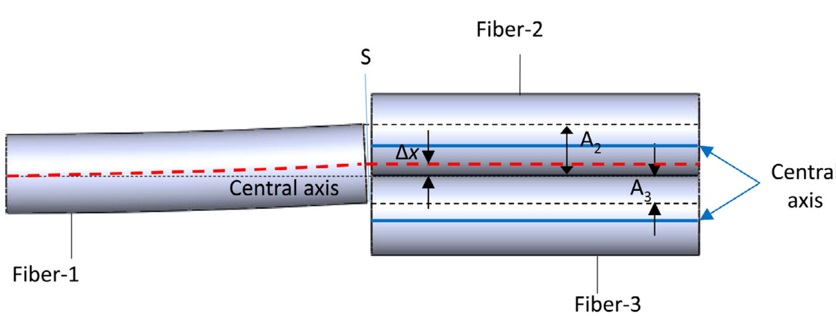

Fig. 2. Graphical expression of angular misalignment of input fiber to the output fibers at S contact plane.