

Variable optical splitter based on wavelength-sensitive components and related intelligent passive optical network

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Abstract This paper proposed a novel variable optical splitter, of which the splitting ratio can be dynamically adjusted according to different wavelengths. A novel intelligent passive optical network (PON) system based on this splitter was also presented. Experimental results demonstrated that the insertion loss can be reduced corresponding to the decrease of the splitting ratio.

Keywords passive optical network (PON), optical splitter, splitting ratio

1 Introduction

The fixed splitting ratio of conventional optical splitter causes inconvenience in many aspects of network planning and maintenance. First, it leads to high costs of spare-part management since tens of types of optical splitters should be prepared. Secondly, unnecessary large power budget is required for both time division multiplexing (TDM) and point to point (PtP) wavelength division multiplexing (WDM) channels in next generation passive optical network2 (NG-PON2) system, due to the inevitable insertion loss of the conventional optical splitter. As the time and wavelength division multiplexed PON (TWDM-PON) and united passive optical network (UniPON) have become the mainstream technologies of NG-PON2 [1,2], it is attractive to investigate how to use the optical power more efficiently in the systems. Thirdly, the adjustment of the splitting ratio and power budget is extremely inconvenient for the deployed PON network.

As to the author's knowledge, only a few variable optical splitters have been reported, based on optoelectronic very large scale integration (Opto-VLSI) [3], slot waveguides [4], polarization signal processing [5], and

field-induced waveguides [6]. However, the devices are mainly active and difficult to integrate.

This paper presented a novel passive optical splitter with dynamically variable splitting ratio. The optical splitter consists of wavelength-sensitive components, and the splitting ratio varies as the wavelength of the optical signal changes. It can be implemented using planar lightwave circuit (PLC) technology [7,8]. Meanwhile, based on this optical splitter, a novel PON system named intelligent PON (iPON) was also proposed, which is capable of dynamic adjustment of the splitting ratio, distribution of optical power and even the network topology. Additionally, it provides considerable potentials for the evolution to the software defined network (SDN) in access domain.

2 A novel optical splitter

Optical splitters consist of cascaded 1:2 coupling components. As shown in Fig. 1(a), the shaded and unfilled triangles represent for the newly proposed and conventional 1:2 coupling components respectively.

For a conventional splitter, each coupling component is insensitive to wavelengths. Thus the splitting ratio remains constant as the wavelength varies.

For the newly proposed splitter, as shown in Fig. 1(a), the input optical power is P_0 and the output powers at the output ports of the first coupling component excluding the excess loss can be expressed as

$$P_1 = P_0 \times \cos^2(kz), P_2 = P_0 \times \sin^2(kz), \quad (1)$$

where k is the coupling coefficient and z is the coupling length. The output power can be sensitive to the wavelength to realize one or more periodic variations from 1260 nm to 1620 nm through changing the core radius in the coupling area [9]. Figure 1(b) illustrates the P_1/P_0 ratio versus wavelength for a single coupling component.

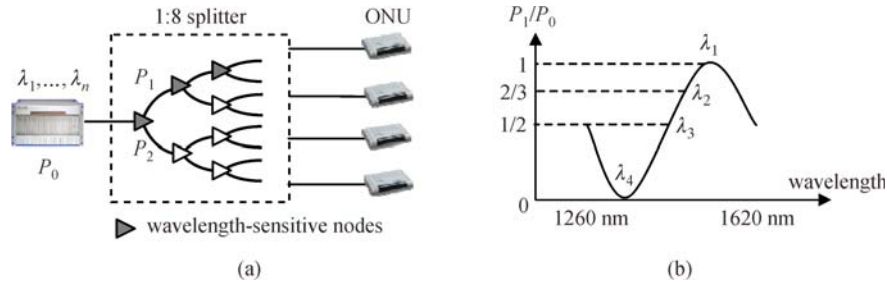


Fig. 1 (a) Configuration of a splitter and iPON system; (b) characteristics of the wavelength-sensitive coupling component in (a). ONU: optical network unit

Ideally, the input power P_0 of the signals with wavelengths of λ_1 and λ_2 can propagate through the component to the upper output port of P_1 with 100% and 66.7% of the input power respectively. As to the signal with a wavelength of λ_3 , the input power is evenly distributed to the output ports of P_1 and P_2 , which is similar to a conventional power splitter. The power of the signal with a wavelength of λ_4 is fully transmitted to the bottom output port of P_2 . Hence, the insertion loss of the proposed splitter also varies with different wavelengths.

The new coupling component can be realized by fused biconical taper (FBT) [9]. Similarly, it can also be realized by PLC of parallel double waveguide type, which is much more difficult to implement.

In this paper, a new configuration using the architecture of Mach-Zehnder interferometer based on PLC with easier implementation was chosen to realize the component, as shown in Fig. 2, wherein ΔL is the optical path difference. The output power P_1 is shown in Eq. (2), wherein n is the index of refraction, which is approximately 1.5.

$$P_1 = P_0 \times \sin^2\left(\frac{k\Delta L}{2}\right) \\ = P_0 \times \frac{1}{2} \left(1 + \cos\left(\frac{2n\pi\Delta L}{\lambda}\right)\right). \quad (2)$$

To achieve periodical variation in the range from λ_a to λ_b , the following equation should be satisfied, wherein m is an integer.

$$n \times \Delta L \times \left(\frac{1}{\lambda_a} - \frac{1}{\lambda_b}\right) = \frac{m}{2}. \quad (3)$$

It can be concluded that if ΔL equals to 3 μm and m equals to 1, P_1 can achieve one period of variation in the

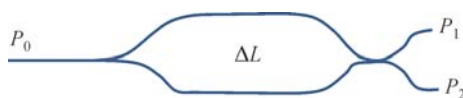


Fig. 2 Configuration of the wavelength-sensitive coupling component

range from 1260 to 1620 nm. As ΔL increases, the cosine term in Eq. (2) results in a smaller period where P_1 varies more quickly with the change of the wavelength, which can be seen in Fig. 4 as an example.

Figure 1 illustrates an example of a splitter with a splitting ratio of 1:8. When only the first coupling component is wavelength-sensitive, the splitting ratio is 1:4 for λ_1 and λ_4 , and the signal outputs from the upper 4 and the bottom 4 ports respectively. At the same time, the insertion loss decreases by about 3 dB. For λ_3 , the splitting ratio is maintained as 1:8. For other wavelengths, the signal power can be distributed between the ports at designed ratios. In one aspect, the function of the splitter can be more flexible when more wavelength-sensitive coupling components are introduced to the structure. For example, it can even assign a dedicated wavelength for one output port. In another aspect, as more periods of variation of P_1 and P_2 are realized through increasing ΔL , various wavelengths can be selected to satisfy the preferred function.

With specific design, the optical splitter consisting of several wavelength-sensitive coupling components can provide flexible splitting ratios which can be adjusted dynamically. At the same time, the novel optical splitter can support both TWDM channels and PtP WDM channels with lower power budget, which combines the advantages of both the conventional optical splitter and the arrayed waveguide grating (AWG).

3 An intelligent PON (iPON)

The iPON system mainly comprises an optical line terminal (OLT) with multiple wavelengths, colorless ONUs, and the proposed variable optical splitter, as shown in Fig. 1(a). The iPON architecture is dynamically reconfigurable. It can reduce the power consumption substantially, and realize the functions of UniPON and TWDM-PON [10] with a lower complexity. The PtP WDM channels of iPON can be used to satisfy the services with large bandwidth demand even including common public radio interface (CPRI) signals between baseband

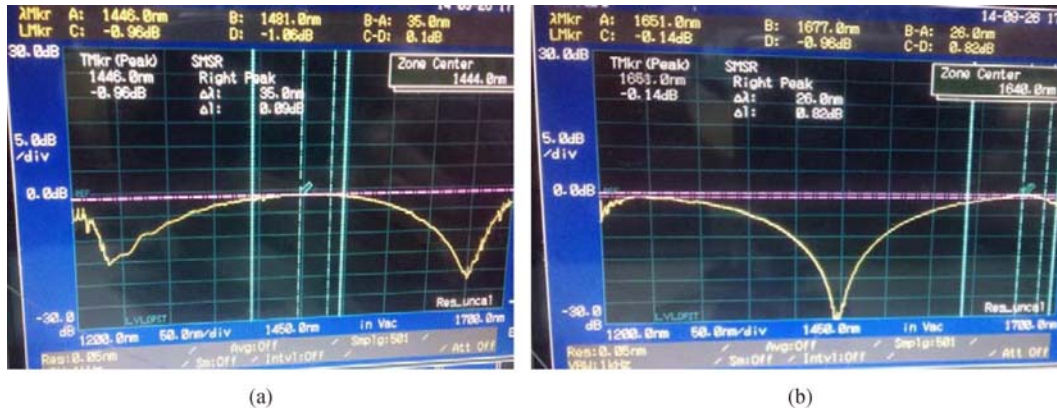


Fig. 3 Insertion loss of the output (a) P_1 and (b) P_2 with one period of variation

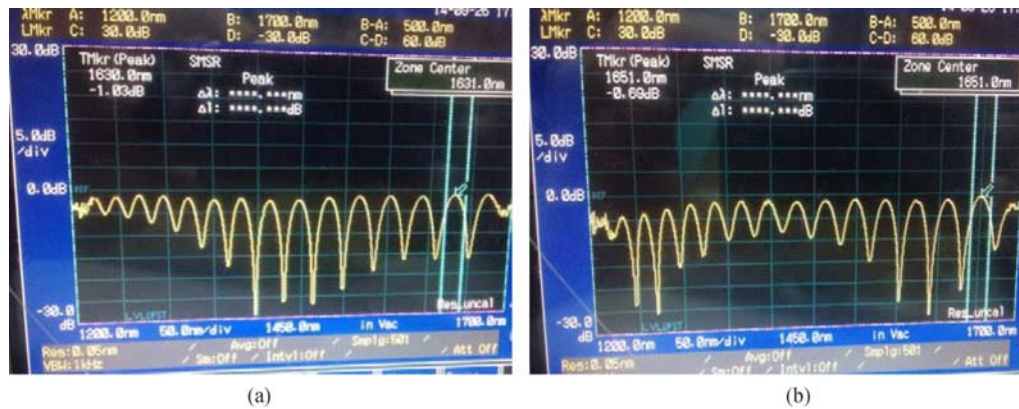


Fig. 4 Insertion losses of the output (a) P_1 and (b) P_2 with multiple periods of variation

unit (BBU) and remote radio unit (RRU). Additionally, the iPON system is flexible to manage the bandwidth or optical power through regulating the splitting ratios by different wavelengths.

The OLT, or a centralized device such as the controller of SDN, is responsible for the calculation, regulation and management of the wavelengths. It is also capable of reconfiguring various parameters of the PON network, including the wavelengths, splitting ratio, network topology, etc. Many other features including wavelength planning, the performance requirement of the system, are out of the scope of the paper and remain to be investigated in the future.

4 Experimental evaluation

Samples of the PLC-type optical splitter with a splitting ratio of 1:2 are fabricated for proof of principle purpose to verify the feasibility of the novel splitter and the iPON. Figure 3 illustrates the experimental results of the insertion losses at the two output ports respectively, where ΔL is designed to be $3 \mu\text{m}$. The lowest insertion loss is less than

0.5 dB, and the power difference between the two output ports for the same input reaches about 20–30 dB. It shows that for specific wavelengths, the splitting ratio of the splitters containing a wavelength-sensitive coupling component can decrease by 50 percent dynamically. Meanwhile, the insertion losses of the corresponding output ports can be reduced by about 3 dB accordingly, assuming the insertion loss of a conventional splitter is 3.5 dB.

Figure 4 presents the experimental results with more periods of variation as ΔL is designed to be $18.6 \mu\text{m}$. The lowest insertion losses of about 1 dB can be achieved for various wavelengths, which indicates that the insertion losses of the expected ports can decrease by about 2.5 dB.

5 Discussion

The proof of principle experiment illustrates that the insertion loss can be altered according to the input wavelength of the novel splitter. This effectively change the splitting ratio. The PLC technology used in this implementation provides a feasible and low-cost approach

for fabrication of this device. The feature of achieving multiple periods of insertion loss alteration make the device a potential candidate for the key element of the future wavelength-sensitive iPON system.

6 Conclusion

We proposed a novel variable optical splitter of which the splitting ratio can be dynamically adjusted through changing the wavelengths of the input signals. The insertion losses of the expected channels can be reduced by approximately 2.5–3 dB when the splitting ratio decreased by 50 percent. The configuration was presented and the experimental results were shown to give a proof of principle demonstration. A reconfigurable system named iPON based on the novel splitter was also proposed. Various parameters of the PON network, including the power budget, splitting ratio and network topology, can be managed and adjusted conveniently.

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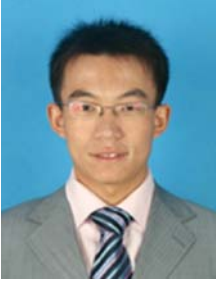
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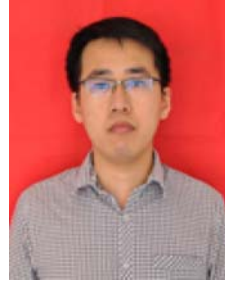
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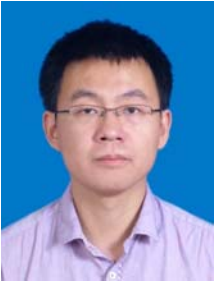
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