

# Channel Enlargement of PON System Using Nonreciprocal Multiplexing Filter Based on CWDM

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*ABSTRACT*—We propose a nonreciprocal filter based on coarse wavelength division multiplexing (CWDM) that reduces the upstream channel insertion loss in a passive optical network (PON). We also propose a method to increase the number of channels/optical network units (ONUs) in PON systems using the proposed filter to reduce the service cost per subscriber. Experimental results show that the PON system with the proposed 4-channel filter can reduce the power budget of the upstream and increase the number of ONUs by 3 to 4 times that of a conventional time-division multiplexing PON.

*Keywords*—Fiber optics communications, optical access network, passive optical network (PON).

## I. Introduction

Optical access networks can provide the greatest bandwidth for both stream traffic directions and relieve bottlenecks in future networks with growing demand. A passive optical network (PON) is a single, shared optical fiber that uses inexpensive passive optical devices in an optical distribution network (ODN) to divide the shared fiber into separated optical network units (ONUs). A telephony PON based on time-division multiplexing (TDM) was developed as a PON [1]. It is a cost-effective solution due to their merits of reducing the amount of installed fiber, use of low fiber-count cables, and the sharing of optoelectronics devices. As a large number of ONUs share an optical line terminal (OLT) and an installed fiber, the cost of a PON system can be reduced in inverse proportion to

the number of ONUs. To increase the number of ONUs connected to an OLT, TDM-PON systems and hybrid wavelength division multiplexing (WDM)/TDM-PON systems are being developed [2]-[5]. A TDM-PON system [2] and WDM/TDM system [3], of which one OLT is shared by 1,024 and 512 ONUs, respectively, have been demonstrated. However, active devices such as optical amplifiers were adapted within the ODN, and their cost and maintenance would be a burden.

A conventional TDM-PON system has an ODN including an optical splitter with the same optical losses for both upstream and downstream signals, the losses of which are proportional to the ONU number. Thus, the system needs high-power optical transmitters or very sensitive receivers to increase the number of ONUs. A conventional TDM-PON system has an upper limitation on the number of ONUs because it is hard for high-power transmitters with high cost to be used in the ONU side.

In this work, we propose a nonreciprocal filter and a channel increasing method in PON systems using the proposed filter based on WDM, in which the ODN has different transmission losses in each direction. The filter can provide an increase in the number of ONUs in a PON system due to the reduced transmission loss for the upstream signal. Although the proposed filter should be added in an ODN, it can dramatically reduce the cost per ONU due to a reduction in the number of OLTs and installed fibers. To test the feasibility of the filter, we demonstrate a 4-channel nonreciprocal filter. It can reduce the power budget of the upstream and increase the number of ONUs by 3 to 4 times. Although WDM-PON and WDM/TDM-PON offer an alternative method to increase the number of ONUs [4], [5] both network types based on a dense WDM-PON require the technology to avoid the need for expensive wavelength-selective optical components in each ONU. Both systems have many transmitters and receivers in the OLT;

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however, the proposed system has one transmitter and one receiver in the OLT side. Therefore, the channel increasing method using a nonreciprocal filter in PONs is cost effective and will be very useful for optical access networks.

## II. Operation Scheme of the Proposed Filter

A TDM-PON system consists of an OLT, an ODN, and several ONUs. A transmitter and a receiver in the OLT are connected to a number of receivers and transmitters in the ONUs. In a conventional TDM-PON system, the downstream/upstream wavelength ranges are 1,480 nm to 1,600 nm and 1,260 nm to 1,360 nm, respectively, and the channel insertion losses of the ODN for downstream and upstream signals are almost the same. To increase the number of ONUs connected to the OLT, the low-power transmitters in the OLT and ONUs should be replaced with high-power transmitters. However, it is hard to use many high-power transmitters in ONUs. Thus, the ideal transmission characteristics of a multiplexing/demultiplexing filter in a TDM-PON having a lot of ONUs are the downstream signal power being uniformly divided into all ONUs and the upstream signals from the ONUs being transmitted to the OLT with no loss.

For the purpose of an ideal filter for TDM-PON, we propose a nonreciprocal filter as a multiplexing/demultiplexing filter that consists of downstream-upstream splitter/couplers (DUCs), a 1:n splitter, and a 1:n WDM filter as shown in Fig. 1. The DUC separates the downstream and upstream signals, and a commercial WDM coupler (or an optical circulator) can be used as a DUC because the downstream and upstream wavelength bands are different from each other. The downstream from the OLT side is inserted into the 1:n splitter through the upper output port of DUC0, and the signal is uniformly divided to all output ports of the splitter. The divided signals are transmitted to all ONUs. The upstream signals of the input ports from the ONU side are inserted into the WDM filter through the lower output ports of the DUCs (DUC1 to DUCn). The inserted signals are combined in the WDM filter and transmitted to the OLT side. If each input port is assigned by a different wavelength, the upstream signals from the ONU

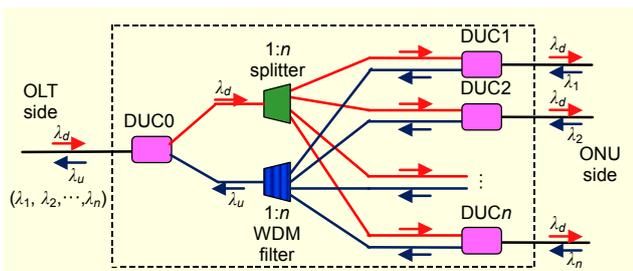


Fig. 1. Schematic diagram of the proposed nonreciprocal filter.

side to the OLT side can be transmitted without loss. Therefore, the proposed filter can allow an increase in the number of ONUs because the downstream signal can be shared by all ONUs, and the upstream signals from the ONUs can be transmitted with little channel insertion loss.

## III. Increasing the Number of Channels

The proposed PON system using the nonreciprocal filter based on WDM is shown in Fig. 2. The OLT consists of one transmitter and receiver, and the ODN is a cascade of the nonreciprocal filter and 1:m splitters. The channel insertion losses of the downstream occur at the nonreciprocal filter and 1:m splitter. Thus, a large power budget for the downstream is needed to support several ONUs, and a high-power transmitter in the OLT is one solution of the large-power budget problem.

In the case of an upstream signal, the transmitters of the ONUs involved in each group have the same wavelength, while the upstream for each group is assigned a different wavelength. The upstream signal has very small channel insertion loss in the nonreciprocal filter, although it has a large channel insertion loss in the 1:m splitter. Therefore, the channel insertion loss of the upstream in the ODN is much smaller than that of the downstream. This transmission characteristic can reduce the power budget of the upstream. Thus, more ONUs can be connected to the OLT using a low-power transmitter instead of a high-power/cost transmitter. As several low-cost ONUs using a low-power transmitter share the OLT and the installed fiber, the service/installed cost per subscriber in the proposed PON system can be reduced.

If upstream wavelengths are assigned by coarse WDM (CWDM) with wide channel spacing, ONU light sources do not require a wavelength control technique, which is needed in WDM-PON systems. Also, wavelength management is unnecessary for either stream because only one wavelength

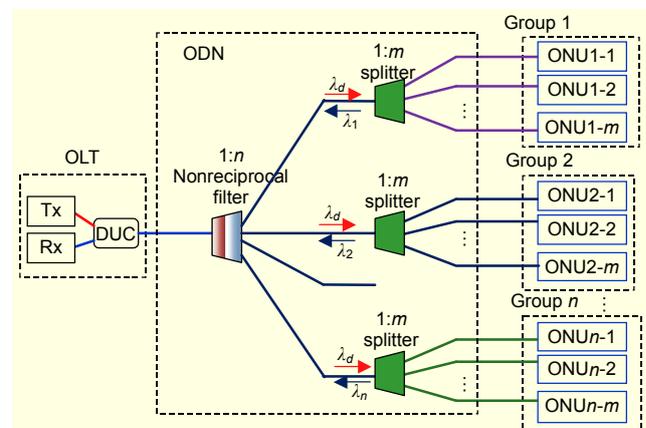


Fig. 2. Structure of a PON system using a nonreciprocal filter.

is used in an OLT and only one wavelength-fixed laser is used in an ONU. However, a proper light source should be installed in an ONU, so the system may have some inventory problems. Nevertheless, fewer wavelengths are used in the proposed scheme than in WDM-PON. By reducing the number of OLTs or light sources/receivers in an OLT, the cost of the proposed system can be more effectively reduced than with a conventional TDM-PON or WDM-PON.

#### IV. Nonreciprocal Filter Design and Characteristics

For a feasibility test, we constructed a 4-channel non-reciprocal filter as shown in Fig. 3. The filter consists of five edge filters, a 1:4 splitter, and a 1:4 CWDM filter. Edge filters (EF0 to EF4, commercial 1300/1500 WDM couplers) were used as DUCs, separating the long wavelength band (> about 1,450 nm) for the downstream and short wavelength band (< about 1,400 nm) for the upstream. Also, a 1:4 CWDM filter was used as a WDM filter. The center wavelengths for each port were 1,290 nm, 1,310 nm, 1,330 nm, and 1,350 nm.

An electro-modulated laser (EML) with -0.22 dBm output power and 1,550 nm wavelength was used as a downstream light source. The laser output was inserted into the 1:4 splitter through the upper port of EF0 and distributed to all output ports of the splitter. The distributed signals were launched in the upper ports of EF1 to EF4. The downstream losses were 8.16 dB, 8.09 dB, 8.23 dB, and 8.24 dB as shown in Table 1. The additional insertion loss was about 1.2 dB for replacing a conventional splitter by a nonreciprocal filter.

Distributed feedback (DFB) lasers with 1,290 nm, 1,310 nm, 1,333 nm, and 1,351 nm were used for the upstream. Each laser output was transmitted to the 1:4 CWDM filter through the lower ports of EF1 to EF4, respectively, and combined at the CWDM filter. The measured channel insertion losses at the EF0 output port were 1.34 dB, 1.26 dB, 1.66 dB, and 1.58 dB as shown in Table 2. If a constructed 1:4 nonreciprocal filter is used instead of a 1:4 splitter with about 7 dB splitting losses in a PON system, the power budget of the upstream can be reduced by more than 5 dB. This means that more ONUs can be connected to one OLT than with conventional TDM-PON systems. The more channels of the nonreciprocal filter used, the greater the number of ONUs that can be supported.

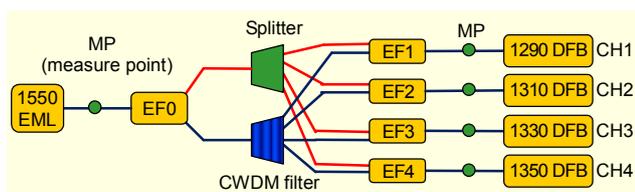


Fig. 3. Experimental setup for filter feasibility test.

Table 1. Measured downstream loss characteristics of the filter.

Channel no.	Wavelength	Splitter loss	Total loss	Additional loss
1	1,550 nm	6.90 dB	8.16 dB	1.26 dB
2	1,550 nm	6.93 dB	8.09 dB	1.16 dB
3	1,550 nm	6.90 dB	8.23 dB	1.33 dB
4	1,550 nm	6.95 dB	8.04 dB	1.09 dB

Table 2. Measured upstream loss characteristics of the filter.

Channel no.	Wavelength	CWDM loss	Total loss	Additional loss
1	1,290 nm	0.80 dB	1.34 dB	0.54 dB
2	1,310 nm	0.60 dB	1.26 dB	0.66 dB
3	1,333 nm	0.91 dB	1.66 dB	0.75 dB
4	1,351 nm	0.95 dB	1.58 dB	0.63 dB

#### V. Conclusion

We proposed a nonreciprocal filter based on CWDM and a method to increase the number of channels in PON systems utilizing the filter. We have demonstrated the feasibility of a 4-channel nonreciprocal filter. The downstream insertion losses of the filter were similar to the splitting loss of conventional TDM-PON systems. However, the upstream losses were much lower than conventional systems. These results show that the filter provides an increase in the number of ONUs connected to one OLT. Also, the system does not require wavelength control technique as the upstream signals are multiplexed by a CWDM with wide channel spacing. Although DUCs and a WDM filter are needed to construct the filter, the service cost per subscriber would be cut dramatically by reducing the number of very high-cost OLTs and the number of installed fibers. Thus, the proposed channel increase method using the filter may provide a cost-effective solution in optical access network fields.

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