

PERFORMANCE EVALUATION OF 1.25×16 GB/S BIDIRECTIONAL DWDM PASSIVE OPTICAL NETWORK BASED ON CYCLIC AWG

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ABSTRACT

We proposed and experimentally demonstrated the cyclic array waveguide grating based bidirectional dense wavelength division multiplexing passive optical network. In the proposed scheme the downstream signal were produced by a wavelength division multiplexing transmitter. The 16 channel proposed network works with 1.25 Gbps downstream signal bit rate and 655 Mbps upstream signal bit rate. The system was proposed over 30 km distance between OLT and ONT using 100 GHz channel spacing in a bidirectional single mode fiber and cyclic array waveguide gratings.

Keywords: Array waveguide grating (AWG), Bit error rate (BER), Dense wavelength division multiplexing Passive Optical Network (DWDM PON), Optical line terminal (OLT), Optical network terminal (ONT).

I. INTRODUCTION

To support the explosive growth of data traffic, various types of wavelength-division-multiplexed passive optical networks (WDM PONs) have been proposed and demonstrated [1]–[5]. This is because WDM PON is attractive due to its large capacity, easy management, network security, and upgradability. However, the network complexity and its subsequent cost have been the most critical issues for the practical deployment. To overcome this problem, it has been proposed to implement WDM PON by using spectrum-sliced incoherent light sources such as light-emitting diodes (LEDs) and amplified spontaneous emission sources [1], [2]. The advantage of such a network would be the use of identical light source at every subscriber site. In addition, these networks could be robust to the optical crosstalk and the temperature-induced drift of the arrayed-waveguide grating (AWG) placed at the remote node (RN) [3], [4]. However, when the spectrum-slicing technique is used, it is often difficult to secure an adequate amount of system margin due to the large slicing loss and low output power of LED. This problem could be relaxed to some extent by using high-power LEDs and sensitive receivers such as avalanche photodiodes (APDs). To solve this problem, it has also been proposed to use optical amplifiers at the central office (CO) [2]. In this letter, we

demonstrate a bidirectional WDM PON using a WDM transmitter. The spectrum-slicing has been achieved automatically at the AWG used for multiplexing and demultiplexing WDM channels. However, when we use cyclic AWG, the spectrum-sliced light would have multiple peaks separated by the free-spectral-range (FSR) of the AWG. Previously, only one of these peaks was selected and used for the transmission to avoid excessive dispersion penalty [1], [2]. However in the proposed BPON network, we have used a 16 channel WDM transmitter with NRZ (non return to zero) modulation format. In the proposed system extinction ratio (ER) of 4 dB has been used with bit rate of 1.25 Gb/s for the downstream signal. In the proposed structure the WDM transmitter has been operated on 1550 nm frequency range with channel spacing of 0.8 nm. For the proposed BPON the upstream signal frequency range of 1360 nm was used with ER 4 dB and channel spacing 0.8 nm. For the upstream signal the system operated with 655 Mbps bit rate. We believe that proposed network could be cost effective due to the use of multiple peaks of spectrum sliced light and bidirectional transmission.

II.DWDM-PON STRUCTURE AND RESULTS

2.1 Proposed Structure

Figure 1 shows the proposed DWDM PON structure. The downstream signals generated by the WDM transmitter in the central office (CO) were multiplexed by the bidirectional Array waveguide grating (AWG) and were fed to a bidirectional SMF (single mode fiber) of 30 KM. After passing through the bidirectional SMF, the signal passes through another cyclic AWG that acts as demultiplexer for downstream signal. The output signals of cyclic AWG were fed at the input of PIN photodiodes. In the receiver section PIN photodiodes has been followed by buffer selectors and BER (bit error rate) analyzers to observe the output. We have used 16 optical transmitters to produce the upstream signals in the ONT section, having 1360 nm to 1348 nm wavelength with 0.8 nm channel spacing. The upstream signals multiplexed by the cyclic AWG have been passed through bidirectional SMF. The cyclic AWG that multiplexes the downstream channels also demultiplexes the upstream channels. By using BER analyzers we observed outputs of demultiplexed upstream signals by using the same PIN photodiodes as used in the OLT section.

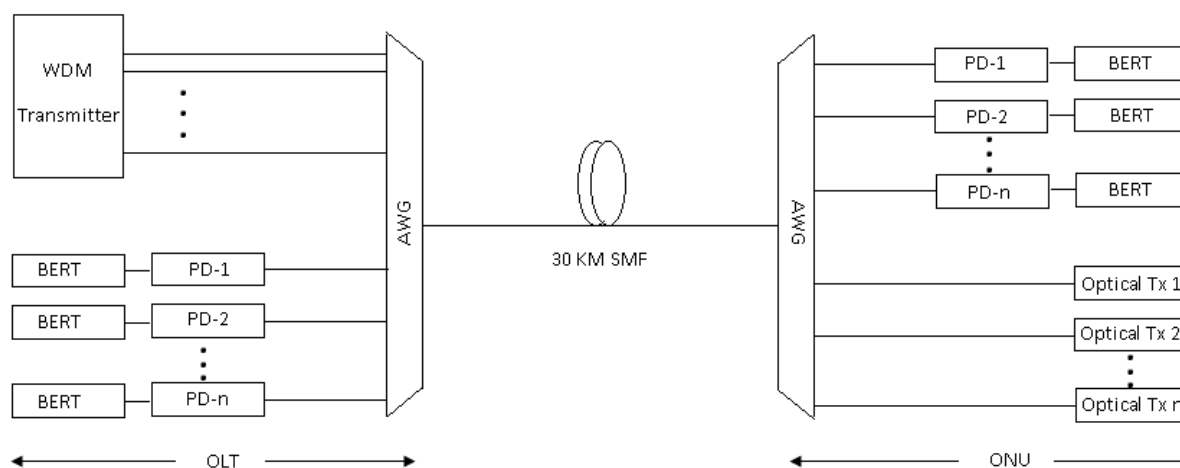


Figure 1 – Proposed structure of DWDM PON using bidirectional AWGs.

2.2 Characteristics of Cyclic Array Waveguide Grating

Arrayed Waveguide Grating (AWG) multiplexers/demultiplexers are planar devices which are based on an array of waveguides with both imaging and dispersive properties. The operation can be understood as follows [6]. When a beam propagating through the transmitter waveguide enters the first Free Propagation Region (FPR) it is no longer laterally confined and becomes divergent. On arriving at the input aperture the beam is coupled into the waveguide array and propagates through the individual waveguides towards the output aperture. The divergent beam at the input aperture is thus transformed into a convergent one with equal amplitude and phase distribution, and the input field at the object plane gives rise to a corresponding image at the centre of the image plane. The spatial separation of different wavelengths is obtained by linearly increasing the lengths of the array waveguides, which introduces a wavelength dependent tilt of the outgoing beam associated with a shift of the focal point along the image plane. If receiver waveguides are placed at proper positions along the image plane, different wavelengths are led to different output ports. Focusing of the fields propagating in an AWG is obtained if the length difference ΔL between adjacent waveguides is equal to an integer number m of wavelengths inside the AWG:

$$\Delta L = m \cdot \frac{\lambda_c}{n_{\text{eff}}} \quad (1)$$

The integer m is called the order of the array, λ_c is the central wavelength (in vacuum) of the AWG, n_{eff} is the effective refractive (phase) index of the guided mode, and λ_c/n_{eff} corresponds to the wavelength inside the array waveguides.

The length increment ΔL of the array gives rise to a phase difference according to

$$\Delta\phi = \beta\Delta L \quad (2)$$

Where

$$\beta = 2\pi\nu n_{\text{eff}}/c \quad (3)$$

is the propagation constant in the waveguides, $\nu = c/\lambda$ is the frequency of the propagating wave, and c is the speed of light in vacuum. The lateral displacement ds of the focal spot along the image plane per unit frequency change $d\nu$ is called the spatial dispersion D_{sp} of the AWG, which is given by [7]:

$$D_{\text{sp}} = \frac{ds}{d\nu} = \frac{1}{\nu_c} \cdot \frac{n_g}{n_{\text{FPR}}} \cdot \frac{\Delta L}{\Delta\alpha} \quad (4)$$

Where n_{FPR} is the (slab) mode index in the Free Propagation Region, $\Delta\alpha$ is the divergence angle between the array waveguides in the fan-in and the fan-out sections, and n_g is the group index of the waveguide mode:

$$n_g = n_{\text{eff}} + \nu \frac{dn_{\text{eff}}}{d\nu} \quad (5)$$

The period in the frequency domain is called the Free Spectral Range (FSR), and

$\Delta\beta \cdot \Delta L = 2\pi$ in combination with (1) leads to:

$$\text{FSR} = \frac{\nu_c}{m} \left(\frac{n_{\text{eff}}}{n_g} \right) \quad (6)$$

An important feature of the AWG-filter characteristics is the passband shape. Flattened and broadened channel transmissions are an important requirement for AWG de/multiplexers. To flatten the passband the simplest method is to use multimode waveguides at the receiver side of an AWG. If the focal spot moves at the AWG output along a broad waveguide, almost 100% of the light is coupled into the receiver to have a flat region of transmission [8]. However, this approach is unfavorable for single-mode systems. Other methods convert the field at the transmitter or receiver into a double image as indicated in Figure 2(a). The wavelength response, which follows from the overlap of this field with the normal mode of a receiver/transmitter waveguide, will get a flat region as shown in Figure 2(b).

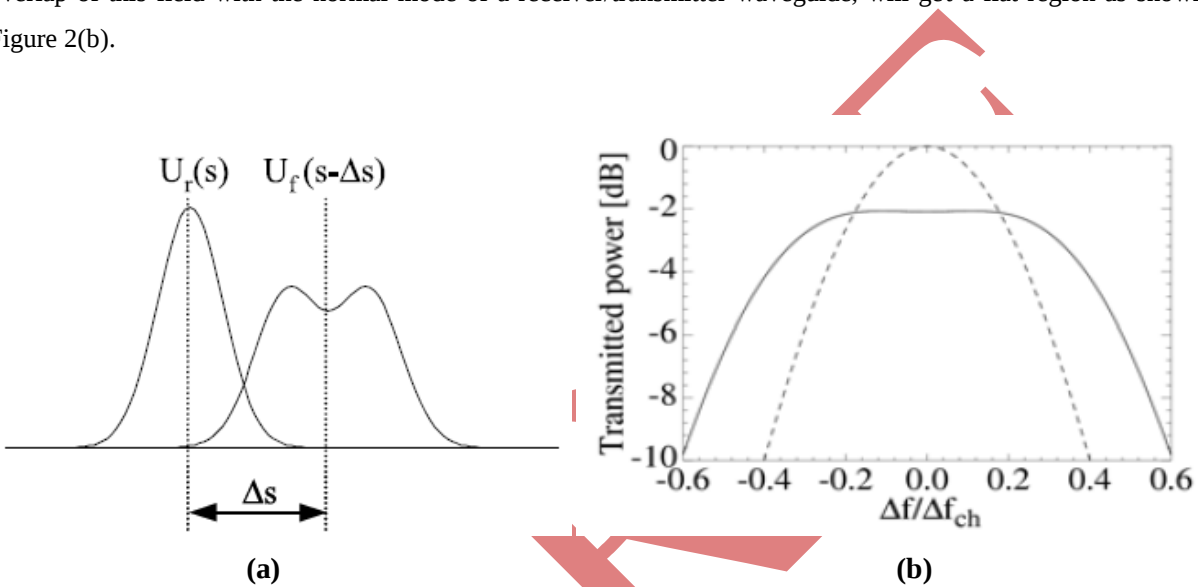


Figure 2 – Wavelength response flattening: (a) Shape of the focal field U_f required for obtaining a flat region in the overlap with the receiver mode U_r , (b) wavelength response obtained by applying a camel-shaped focal field (the dashed curve indicates the non-flattened response obtained by applying a non-modified focal field, i.e. $U_f = U_r$)

An interesting device is obtained if the AWG is designed with N input and N output waveguides and a free spectral range equal to N times the channel spacing. With such an arrangement the device behaves cyclical: a signal disappearing from output N will reappear at output 1, if the frequency is increased by an amount equal to the channel spacing. Such a device is called a cyclical wavelength router [9]. Figure 3 illustrates its functionality. Each of the N input ports can carry N different frequencies. The N frequencies carried by input channel 1 (signals a_1 - a_4 in Figure 3) are distributed among output channels.

The general AWG behavior is described by (7), where θ_{IN} and θ_{OUT} represents the angles between the respective slab centre axis and the attached input/output waveguides.

$$\theta_{i,IN} = \frac{m}{n_{sd}} \left\{ \lambda_i - \lambda_c \left[1 + \frac{1}{n_{wg}} \frac{dn_{wg}}{d\lambda} (\lambda_i - \lambda_c) \right] \right\} - \theta_{i,OUT} \quad (7)$$

In this equation, λ_i is the signal wavelength and m is the grating order at λ_i , λ_c is the design centre wavelength at order m , d is the grating pitch, and n_s and n_{wg} are the effective refractive indices at λ_c of the slab and the grating waveguides, respectively. This equation takes into account also the chromatic material dispersion by a linear fit of n_{wg} around λ_c (given in square brackets). The input/output waveguide positions at both slabs are $x=\theta f$, where f is the slab focal length.

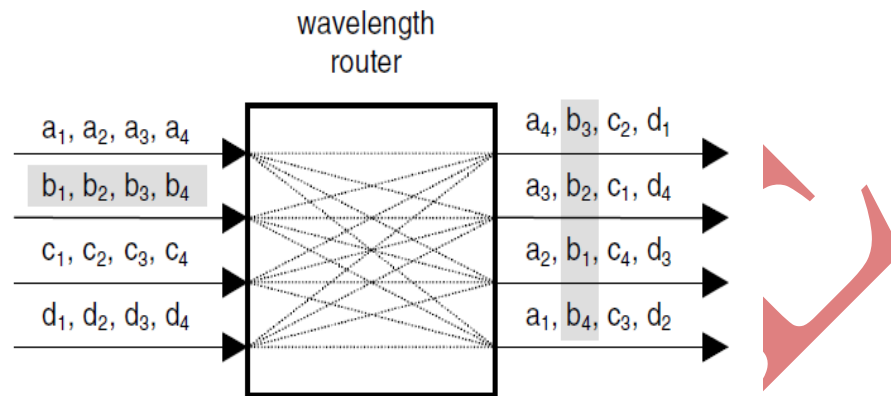


Fig. 3 Schematic diagram illustrating the operation of a wavelength router

2.3 Transmission performance

In the proposed system a 16 channel WDM transmitter produces the downstream signals in the 1500 nm range with 100 GHz channel spacing. An extinction ratio of 4 dB has been used for the downstream signal. WDM transmitter produces the 16 downstream channels at input power of -3dBm. The driving amplitude was modulated by a 1.25Gbps non return to zero (NRZ) format. As the bit rate is enhanced from 1Gbps to 1.25Gbps and transmission length is also increased from 10 km to 30 km [10].

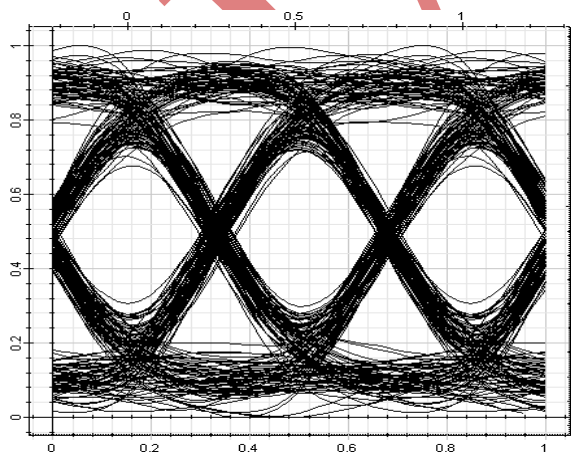


Figure 4 – Eye diagram of downlink at 4dB ER

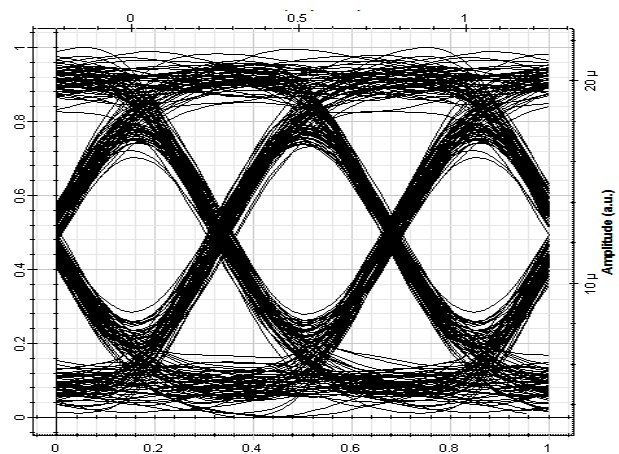


Figure 5 – Eye diagram of downlink at 6dB ER

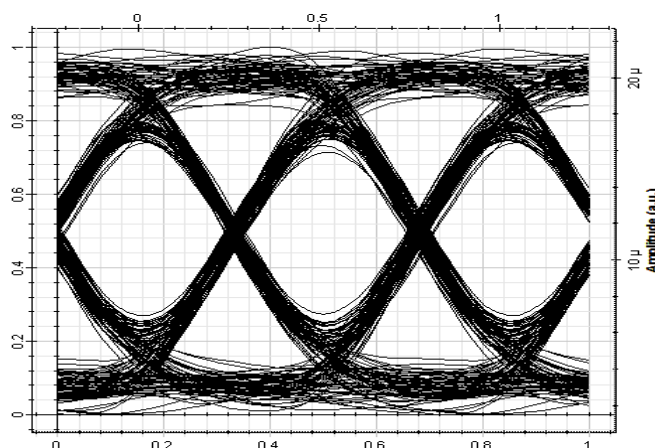


Figure 6 – Eye diagram of downlink at 8dB

The signal power after the losses of two AWGs and bidirectional SMF was reduced to -13dBm before launching into each ONU. The bidirectional single mode fiber has been operated with 16.75ps/nm/km dispersion and an attenuation of 0.2dB/km. For producing the upstream signal the ONU has been composed of receiving module and an optical transmitter that also operates with -3dBm input. Optical transmitter produces the same power signal as produced by WDM transmitter at the OLT with extinction ratio of 4dB.

The receiving module for each channel at both OLT and ONT consists of a PIN photodiode, a Bessel filter, a 3R generator and a BER analyzer. At 4dB extinction ratio Q-factor of 5.483 and bit error rate of 10^{-8} has been obtained for downstream signal and for the upstream signal the Q-factor of 8.544 and bit error rate of 10^{-18} have been obtained. Figure 4, 5 and 6 show the eye diagrams for downstream signal at extinction ratio of 4dB, 6dB and 8dB respectively. In eye diagram of figure 5 bit error rate of 10^{-9} and Q-factor of 5.849 has been obtained at 6dB ER. And in eye diagram of figure 6 bit Error Rate of 10^{-10} and Q-factor of 6.03 has been obtained at 8dB ER. Figure 7 shows the relation between input power and BER at extinction ratio 4dB and 6dB and Figure 8 shows the relation between input power and Q-factor.

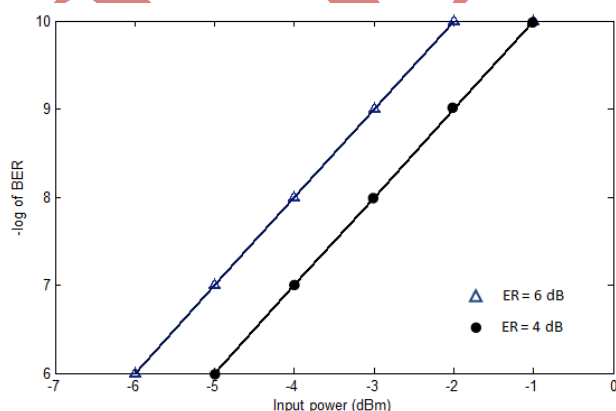


Figure 7 – Relation between input power and BER at 4dB and 6dB

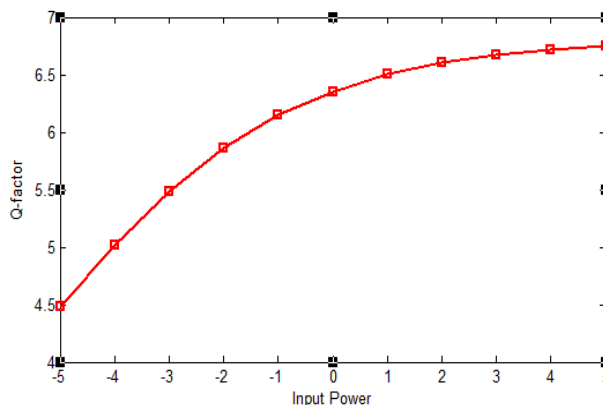


Figure 8 – Relation between input power and Q-factor

III. CONCLUSION

The bidirectional DWDM PON link using WDM transmitter and cyclic AWG was demonstrated and investigated. The 16 channel bidirectional passive optical network has been operated on downstream bit rate of 1.25Gbps and the upstream bit rate of 622Mbps. It is observed from the eye diagrams of figures 4, 5, and 6 that as the extinction ratio was increased from 4 dB to 6 dB and 8 dB respectively the bit error rate and quality factor were improved. Graphical representation in figures 7 and 8 shows the variation of downstream Bit error rate and Q-factor with respect to the input power.

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