An OTDM-To-WDM Converter Using Optical Fourier Transformation

Khin Su Myat Min, Zaw Myo Lwin, Hla Myo Tun

Abstract: We demonstrate serial-to-parallel conversion of 40 Gbps optical time division multiplexed (OTDM) signal to 4x10 Gbps wavelength division-multiplexed (WDM) individual channels by using Optical Fourier Transformation (OFT) method. OFT is also called time lens technique and it is implemented by the combination of dispersive fiber and phase modulation. In this research, electro-optic phase modulator (EOM) is used as time lens. As our investigations, simulation results and bit error rate (BER) measurements are expressed.

Index terms: OTDM to WDM, Optical Fourier Transformation (OFT), serial-to-parallel conversion, electro-optic time lens.

I. INTRODUCTION

Nowadays, the use of internet based services increases significantly, it leads to the growth of network traffic. So, optical networks encounter a problem of requiring enhanced capacity to cope with the increased traffic [1,2]. In this case, serial-to-parallel conversion becomes popular to fulfill the demand for optical communication networks [1,2]. Multiplexing techniques are used to achieve better capacity for the system; it allows multiple signal channels to travel through a single medium. OTDM is a powerful technology to upgrade the system bandwidth, it combines a number of low data rate channels to get ultra-high speed transmission rate [1] whereas in WDM system, many wavelength channels share a single fiber. It is a basic technology for optical networks as well as it is the first multiplexing technique in optical communication systems. Moreover, WDM is a flexible technology; it has transparency with data format and data rate and also it reaches advanced stage of technology. However, it has some limitations in channel spacing and number of channel because of nonlinear effects [3]. Thus hybrid networks are attractive for better performance. Different approaches have been used for OTDM to WDM conversion process and these are based on nonlinear effects and subsystems such as nonlinear optical loop mirror [4], four-wave mixing (FWM) in highly nonlinear fiber (HLNF) [1], cross-phase modulation (XPM) [5] and Optical Fourier Transformation (OFT) [2,6,7]. These methods require high optical power and nonlinear medium for nonlinear process, so system configuration is complex. OFT is built with dispersion and phase modulation (time lens) [2,6,7]. In this method, fiber is used as dispersive medium and nonlinear process is usually used for phase modulation [2,6,7]. Therefore, as our contribution, in this research we use OFT method with electro-optic time lens instead of nonlinear process. This makes the system less complex.

II. OPERATION PRINCIPLE

Optical Fourier Transformation (OFT) relies on the analogy called space-time duality which is the similarity of equations between paraxial diffraction of propagating wave in space domain and narrow band dispersion in time domain [8]. Also time lens is analogous to a thin lens which performs Fourier transformation of an object placed one focal length apart from the lens. But a thin lens produces spatially quadratic phase shift whereas a time lens provides temporally quadratic phase shift [6]. Then the focal length in space domain is similar to the dispersive length in time domain. For time to frequency conversion purpose, OFT is constructed by a dispersive fiber followed by phase modulation [2,6,7,9].

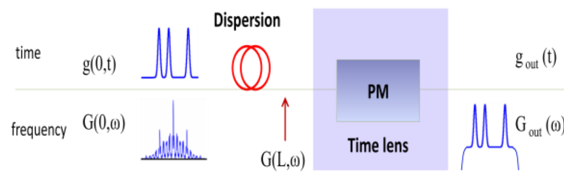


Fig.1. *Basic principle for time to frequency conversion process using OFT technique*

In Fig.1 g (0,t) is the input signal to the Fourier processor and G_{out} (ω) is the output spectrum which is related by Fourier transform of the input. We will describe the mathematical proof for time to frequency conversion process or OFT technique. First, the signal travels through the dispersive fiber with second-order chromatic dispersion β_2 and length L. The action of dispersive element is described in frequency domain.

$$F(L,\omega) = \exp\left(\frac{i\beta_2 L\omega^2}{2}\right) \quad (1)$$

Then the dispersive signal is input to the phase modulator. The transfer function of time lens producing quadratic phase shift is expressed with linear chirp K.

$$P(\omega) = \sqrt{\frac{2\pi i}{K}}\exp\left(\frac{-i\omega^2}{2K}\right) \quad (2)$$

Suppose g (0, t) is the input waveform to the Fourier processor, it is propagated through the dispersive medium. The output of fiber in frequency domain is

$$G(L,\omega) = G(0,\omega)\,F(L,\omega) \quad (3)$$

Then the dispersive signal is quadratically phase modulated in the time lens, the output is

$$G_{out}(\omega) = \frac{1}{2\pi}G(L,\omega) * P(\omega) \quad (4)$$

$$= \frac{1}{2\pi}\int_{-\infty}^{\infty} G(L,\omega')P(\omega-\omega')\,d\omega'$$

$$= \sqrt{\frac{i}{2\pi K}}\int_{-\infty}^{\infty} G(L,\omega')\exp\left(-\frac{i(\omega-\omega')^2}{2K}\right)d\omega'$$

$$= b\int_{-\infty}^{\infty} G(0,\omega')\exp\left(i\frac{(\beta_2 LK-1)\omega'^2+2\omega\omega'}{2K}\right)d\omega'$$

Where, $b=\sqrt{\frac{i}{2\pi K}}\exp\left(-\frac{i\omega^2}{2K}\right)$

When the condition $K=\frac{1}{Disp}$ is satisfied and the dispersion is $Disp=\beta_2 L$.

$$G_{out}(\omega)=b\int_{-\infty}^{\infty} G(0,\omega')\exp\left(i\frac{\omega\omega'}{K}\right)d\omega' \quad (5)$$

Time and frequency are related by, $t={}^{\omega}/_{K}$,

$$G_{out}(\omega)=b\int_{-\infty}^{\infty} G(0,\omega')\exp(it\omega')\,d\omega' \quad (6)$$

Finally, the output spectrum of OFT is

$$G_{out}(\omega)=2\pi b g(0,t) \quad (7)$$

The last equation means that the output of OFT in frequency domain is proportional to the input in time domain. At the output spectrum, the tributaries information appears at different wavelength allocations with spacing $\Delta\omega=\Delta t K$, which is also called time to frequency conversion factor, where $\Delta\omega$ is angular frequency spacing and Δt is time spacing [6,7]. For the system time lens is the electro-optic modulator, therefore the phase shift is determined by $\Delta\phi={}^{\pi V}/_{V_\pi}$ where V is the sinusoidal applied voltage to the modulator and V_π is the half-wave switching voltage of the modulator which is applied to get π phase shift [9,10]. As lens induces parabolic phase modulation, the parabolic part of the sine wave is needed to define. This region exists under the peak of the sine wave and can be determined by $\tau_a\approx{}^{1}/_{\omega_m}$, τ_a is the aperture time (the region that can provide quadratic phase) and ω_m is the modulating frequency [9]. Thus the signal outside the time window will not be affected by quadratic phase modulation.

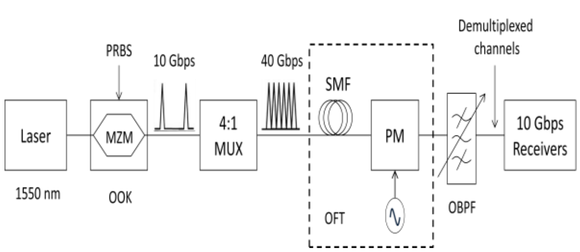


Fig.2. *Block diagram of the proposed system*

Fig 2 shows the setup for time to frequency converter. The figure contains two parts, OTDM transmitter and OFT for serial to parallel conversion process. At the transmitter, CW laser with 1550nm wavelength is used, then the laser output is encoded with 10 Gbps repetition rate PRBS (Pseudo-Random Bit Sequence Generator) in a Mach-Zehnder Modulator (MZM). The inputs to the multiplexer are RZ (return to zero) signals with Gaussian pulse which has pulse width of 8.25ps (33 percent of the bit duration). The output of multiplexer is OTDM multiplexed signal, it is applied to the Fourier processor performing time to frequency mapping of the input signal. In OFT, single mode fiber is used for dispersion with dispersion value D of 17 ps/(nm.km) (ITU-T recommendation G-652). The second order dispersion coefficient β_2 is -21.6 ps^2/km and the length of fiber is 1.84 km which is used to get channel spacing of 100 GHz (ITU-T G-694/ spectral grid for WDM). In order to demultiplex four channels, the phase modulation index of 2π is applied to the phase modulator with 10GHz modulation frequency. For the control to the modulator, we used two settings at the RF signal which are 180 degree out of phase to each other. Finally, each 10 Gbps output WDM channel is extracted from broaden output spectrum by using tunable optical band pass filter (OBPF) at different wavelengths.

III. SIMULATION RESULTS

Simulations are carried out by Optisystem software. Fig.3 and Fig.4 compare input spectrum with 0 dBm input power at 1550nm center wavelength and broadened OFT output spectrum by the effect of phase modulation.

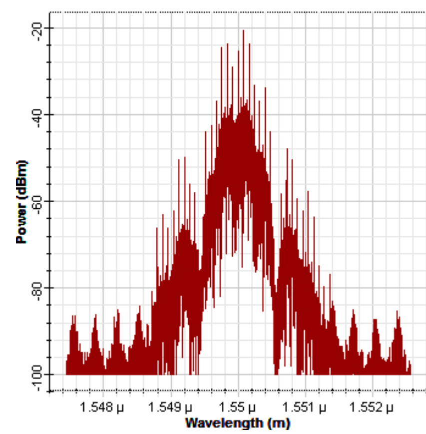


Fig.3. *Input spectrum*

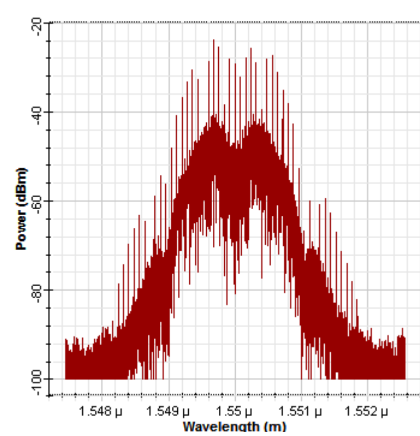
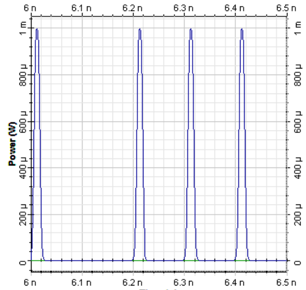


Fig.4. *OFT output spectrum*

Fig.5 shows the four input tributaries to the OTDM transmitter. Each signal is 10 Gbps RZ signal with pulse width of 8.25 ps. All of four channels combine to form 40 Gbps OTDM signal.



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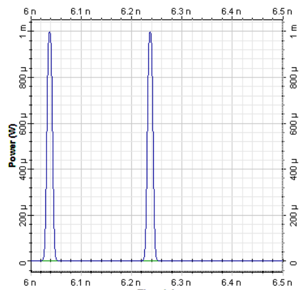

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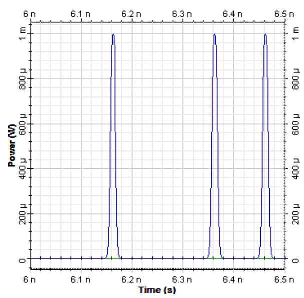

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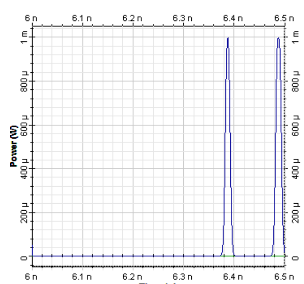
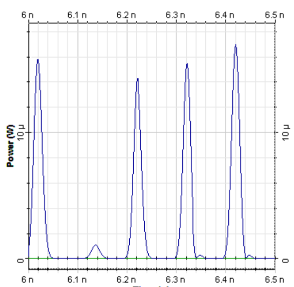


(d)

Fig .5. *Four input channels to OTDM transmitter.*

Fig.6 presents output WDM channels extracted from output OFT spectrum by 0.24nm band pass filter.



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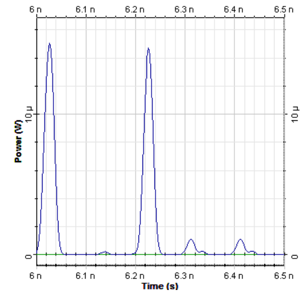

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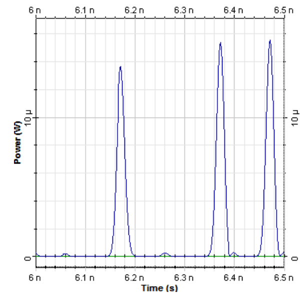

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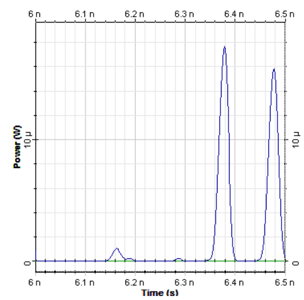
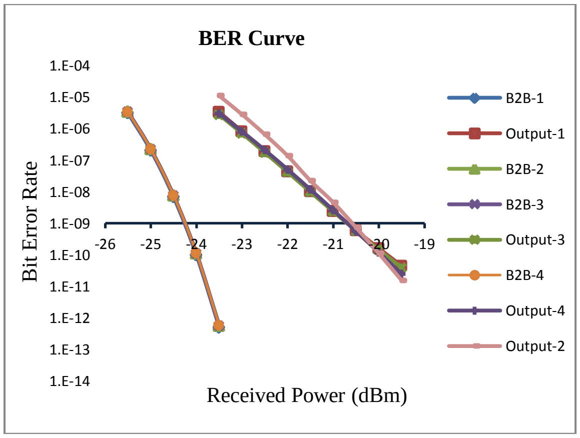


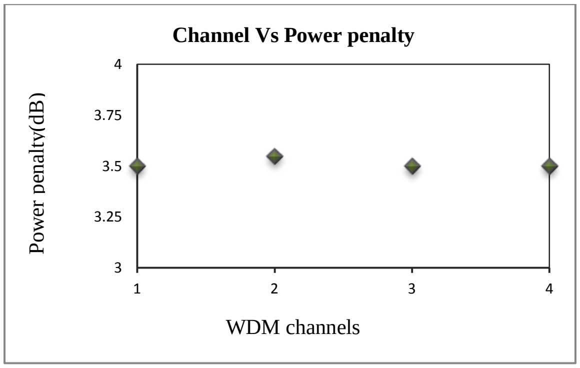
(d)

Fig.6. *10 Gbps demultiplexd WDM channels*

Fig.7 describes the performance of the system. Full demultiplexing of four channels is achieved with power penalties around 3.5 dB at BER of 10^{-9}.



(a)



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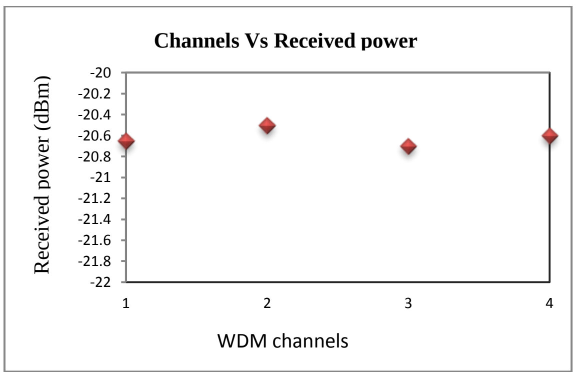

(c)

Fig.7. *(a) BER measurement of the system for four output channels and back to back,(b) channel versus power penalty and (c) channel versus received power at BER of* 10^{-9} *condition.*

IV. CONCLUSION

In this paper, demultiplexing of 40 Gbps OTDM to 4x10 Gbps WDM is described. OFT is implemented with electro-optic time lens for simple system configuration. All channels are demultiplexed successfully with power penalty of approximately 3.5dB but we use two settings of RF signal to the time lens to implement four- channel demultiplexing.

ACKNOWLEDGEMENT

The author acknowledge to her supervisor for his invaluable advices and guidance. The author also would like to thank all her teachers in Department of Electronic Engineering for their helpful suggestions through the research.

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