High Channel Arrayed Waveguide Grating (AWG) in Wavelength Division Multiplexing Passive Optical Networks (WDM-PONs)

Abd El–Nasar A. Mohammed[1], Abd El–Fattah A. Saad[2], and Ahmed Nabih Zaki Rashed[3]

1. [1,2,3]Electronics and Electrical Communication Engineering Department
Faculty of Electronic Engineering, Menouf, Menoufia University, 32951, EGYPT

Summary
In the present paper, high channel arrayed waveguide grating (AWG) in wavelength division multiplexing passive optical networks (WDM-PONs) are deeply studied over wide range of affecting parameters. Two multiplexing methods are applied, Space Division Multiplexing (SDM) and Wavelength Division Multiplexing (WDM), where 20-40 channels are processed to handle the product of bit rate for planar waveguide cables of multi-links (4-12 links/core) using Soliton transmission technique.

Key words:
WDM-PONs; AWG; SDM; WDM; Soliton bit rate.

1. Introduction

The wavelength-division multiplexed passive optical network (WDM-PON) is emerging as a promising broadband access technique that will meet the ever-increasing bandwidth requirement for the end users [1, 2]. Recently, peer-to peer Internet applications, such as sharing of data or video among peers, as well as virtual private connections among branch sites in the enterprise arena, are getting more popular. Therefore, it is anticipated that the amount of traffic among the subscribers in a passive optical network (PON) will get [3].

Significantly large. Nevertheless, conventional WDM-PON architectures only support both the downstream and the upstream transmission with a dedicated set of wavelength channels for communications between the optical line terminal (OLT) and each optical network unit (ONU). The ONUs cannot directly communicate with each other [4]. The inter-ONU traffic must first be transmitted, via the upstream carrier, back to the OLT, where it is electronically routed and modulated on the respective downstream carriers that are destined to other ONUs. Therefore, it is desirable to provide direct connections for internetworking of ONUs in WDM-PONs [5]. Wavelength division multiplexing (WDM) is currently deployed in high-capacity, long-haul fiber-optic transmission systems to support multiple high-speed channels. WDM takes advantage of the enormous bandwidth offered by optical fiber while allowing individual wavelength channels to be utilized at bit rates suited to low-cost electronic components [6, 7]. Such devices comprise a small number of components, including the multiplexer/demultiplexer (MUX/DEMUX), various switches and other functional devices. The arrayed waveguide grating (AWG) has become increasingly important in these types of channel-selective routing devices for WDM signals [8].

In the present study, we have theoretically and parametrically investigated the basic Soliton transmission technique to transmit 20-40 channels of multi links (4-12 links/core) based on two multiplexing methods namely space division multiplexing (SDM) and wavelength division multiplexing (WDM) in the interval of 1.45 μm to 1.65 μm for high channel AWG employed in WDM-PONs.

From this section, input the body of your manuscript according to the constitution that you had. For detailed information for authors, please refer to [1].

2. Simplified Network Architecture Model

The network architecture is shown in Fig. 1. It is based on two cascaded LiNbO3 arrayed waveguide gratings (AWGs). The first stage is an N×N AWG located at the optical line terminal (OLT) or outdoor. The functionality of this AWG is to route optical signals generated by the OLT vertical cavity laser stack to each of the network branches to which the OLT will serve. The second stage is a 1×M AWG located at the remote node. Its task is to demultiplex the M incoming wavelengths to each of the output ports, which connect to the optical network units (ONUs) or optical network channels. The entire network routing intelligence is located at the OLT in order to provide easy upgradeability and easy integration with the backbone. The two cascade AWGs are connected to each other by the single mode optical fiber links. The Soliton bit rate either per single optical fiber link or per optical

Manuscript received January 5, 2009
Manuscript revised January 20, 2009

network units or channels (ONCs) are depicted in the series of the figs. (4-11).

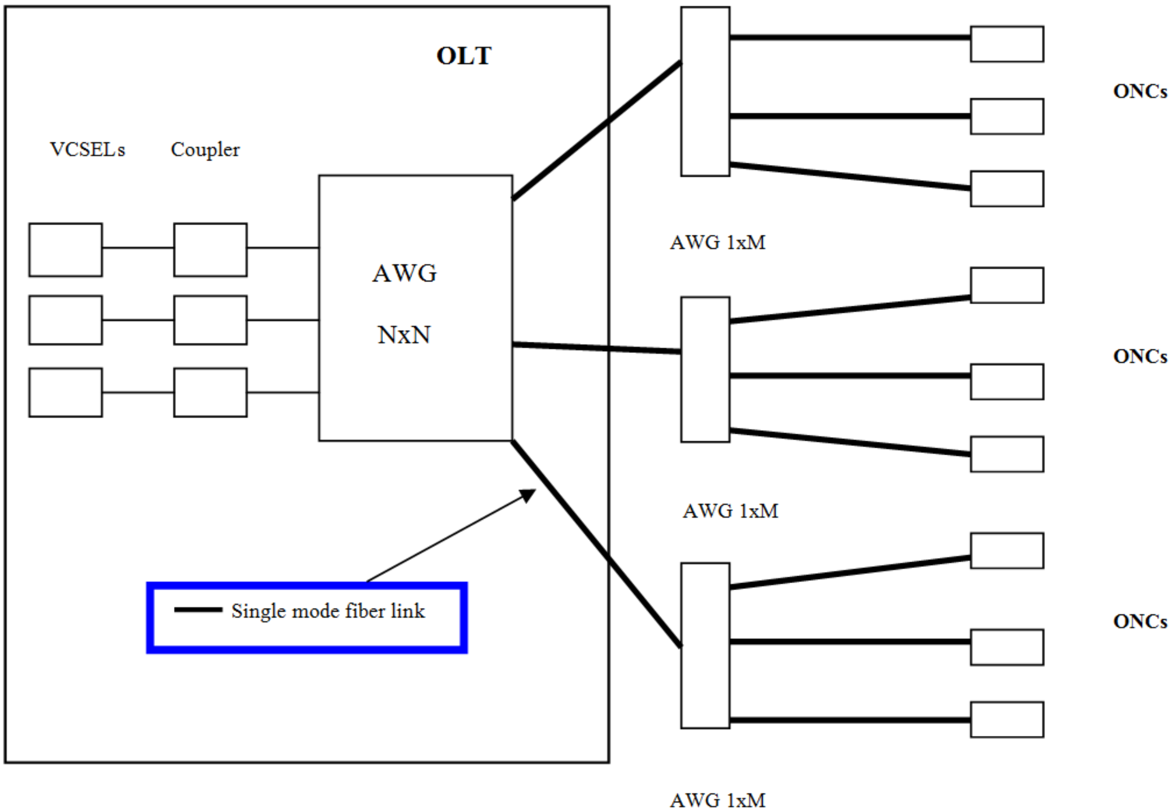

Fig. 1. Simplified network architecture model.

3. Paragraphs and Itemizations

The investigation of both the thermal and spectral variations of the waveguide refractive index (n) require Sellmeier equation under the form [9]:

$$n^2 = A_1 + A_2F + \frac{A_3 + A_4F}{\lambda^2 - (A_5 + A_6F)^2} + \frac{A_7 + A_8F}{\lambda^2 - A_9^2} - A_{10}\lambda^2 \quad (1)$$

where λ is the optical wavelength in μm and $F = T^2 - T_0^2$. T is the temperature of the material, K, and T_0 is the reference temperature and is considered as 300 K. The set of parameters of Sellmeier equation coefficients, $LiNbO_3$, are [9]:

A_1=5.35583, A_2=4.629 x 10^{-7}, A_3=0.100473, A_4=3.862 x 10^{-8}, A_5=0.20692, A_6= -0.89 x 10^{-8}, A_7=100, A_8=2.657 x 10^{-5}, A_9=11.34927, and A_{10}=0.01533.

Equation (1) can be simplified as the following expression:

$$n^2 = A_{12} + \frac{A_{34}}{\lambda^2 - A_{56}^2} + \frac{A_{78}}{\lambda^2 - A_9^2} - A_{10}\lambda^2 \quad (2)$$

$A_{12}=A_1+A_2$ F, $A_{34}=A_3+A_4$ F, $A_{56}=A_5+A_6$ F, and $A_{78}=A_7+A_8$ F.

Then the second differentiation w. r. t λ yields:

$$\frac{d^2n}{d\lambda^2} = -\frac{1}{n}\left[\frac{A_{34}\left[\left(\lambda^2 - A_{56}^2\right) - 4\lambda^2\right]}{\left(\lambda^2 - A_{56}^2\right)^3} + \frac{A_{78}\left[\left(\lambda^2 - A_9^2\right) - 4\lambda^2\right]}{\left(\lambda^2 - A_9^2\right)^3} + A_{10}\right] \quad (3)$$

The total B.W is based on the total chromatic dispersion coefficient D_t where:

$$D_t = D_m + D_w \quad (4)$$

D_m : is the material dispersion coefficient in sec/m^2, and

D_w : is the waveguide dispersion coefficient in sec/m^2.

Both D_m, D_w are given by (for the fundamental mode):

$$D_m = -\frac{\lambda}{C}\left(\frac{d^2n}{d\lambda^2}\right), \quad \text{sec/m}^2 \quad (5)$$

$$D_w = -\left(\frac{n_{cladding}}{C\,n}\frac{\Delta n}{\lambda}\right)Y, \quad \text{sec/m}^2 \quad (6)$$

C: is the velocity of the light, 3 x10^8 m/sec, n : is the core refractive-index, Y: is a function of wavelength, λ [10], the relative refractive-index difference Δn is given by:

$$\Delta n = \frac{n - n_{cladding}}{n} \quad (7)$$

Soliton propagation as a real technique attracted the attention for long distance optical communication systems of high capacity [11]. Based on the model of [12], the condition to obtain sustained soliton is given by:

$$P_{so}\,\tau_{os}^2 = 0.597\left(\frac{\lambda}{1.54}\right)\left(\frac{A_e}{20}\right)\left(\frac{3.2\,x10^{-20}}{n_2}\right)|D_t| \text{ , watt.psec}^2 \quad (8)$$

λ: is the operating optical wavelength, μm, P_{so}: is the average power, watt, A_e: is the effective area, μm^2, $|D_t|$: is the total chromatic dispersion coefficient, sec/m^2, τ_{os} : is the initial pulse width, psec, and n_2 is the nonlinear refractive-index coefficient and is estimated on the same bases of Ref. [13] as:

$$n_2 = 25\varepsilon_0\left[n\left(n^2-1\right)\right]N_0 \text{ , m}^2/\text{V}^2 \quad (9)$$

For lithium niobate ($LiNbO_3$) material, N_0 is taken as 2.7994 x 10^{-13}. Taking into account that the pulse width at distance equals 10 τ_{os}, then the soliton transmission bit rate per channel is given by the following relation:

$$B_{rschannel} = \frac{1}{10\,\tau_{os}} = \frac{0.1}{\tau_{os}} \text{ , Gbit/sec/channel} \quad (10)$$

Then we can get the soliton transmission bit rate per link is given by:

$$B_{rslink} = \frac{0.1\,N_{link}}{\tau_{os}} \text{ , Gbit/sec/link} \quad (11)$$

N_{Link} : is the total number of links in the core of the waveguide, and $N_{Channel}$: is the total number of channels per link.

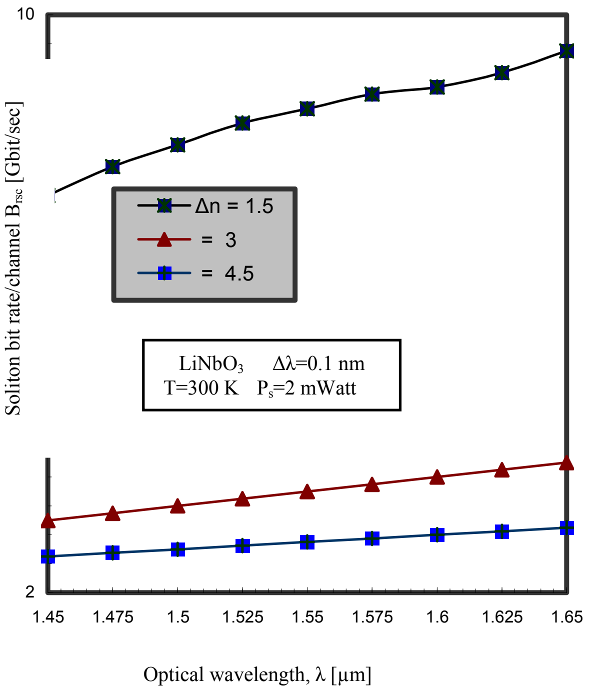

Fig. 4. Variations of soliton bit rate/channel, B_{rsc}, against variations of optical wavelength at the assumed set of parameters.

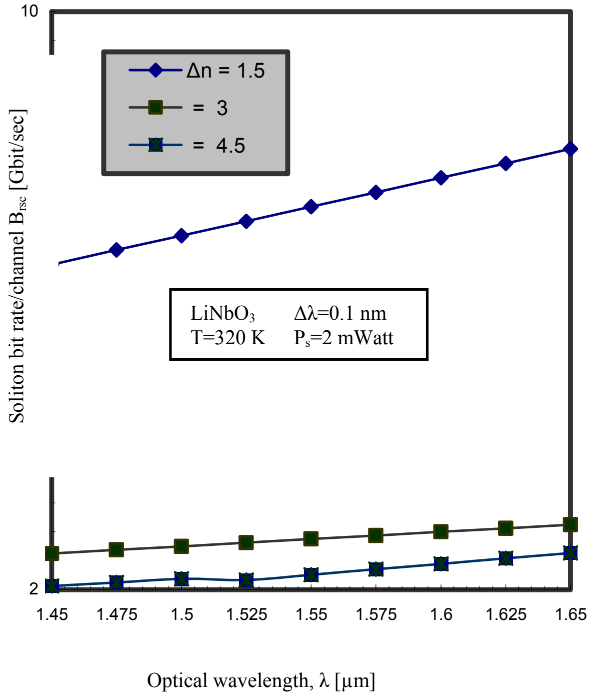

Fig. 5. Variations of soliton bit rate/channel, B_{rsc}, against variations of optical wavelength at the assumed set of parameters.

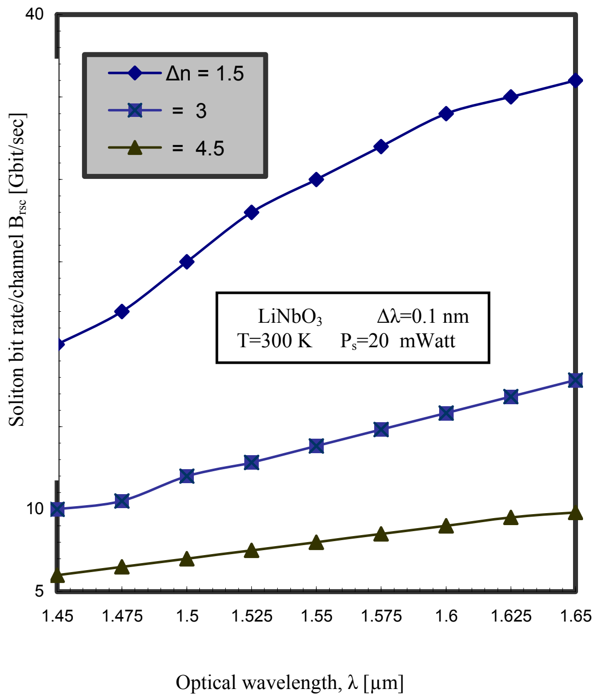

Fig. 6. Variations of soliton bit rate/channel, B_{rsc}, against variations of optical wavelength at the assumed set of parameters.

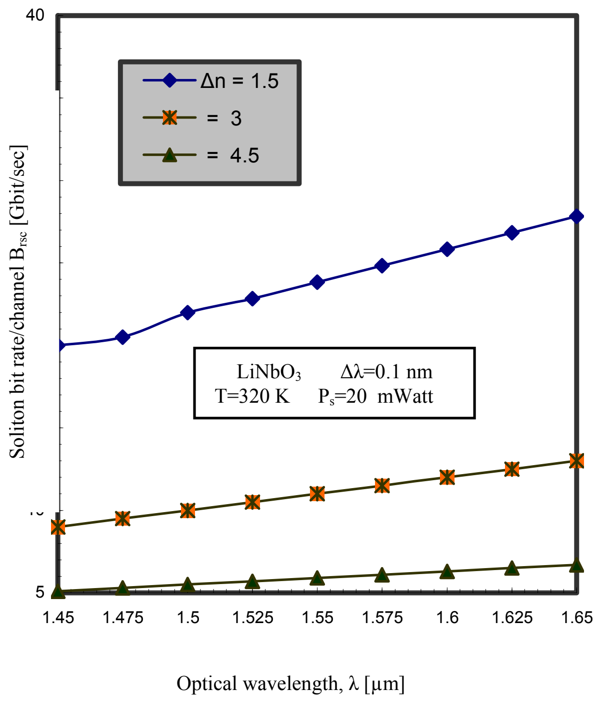

Fig.7. Variations of soliton bit rate/channel, B_{rsc}, against variations of optical wavelength at the assumed set of parameters.

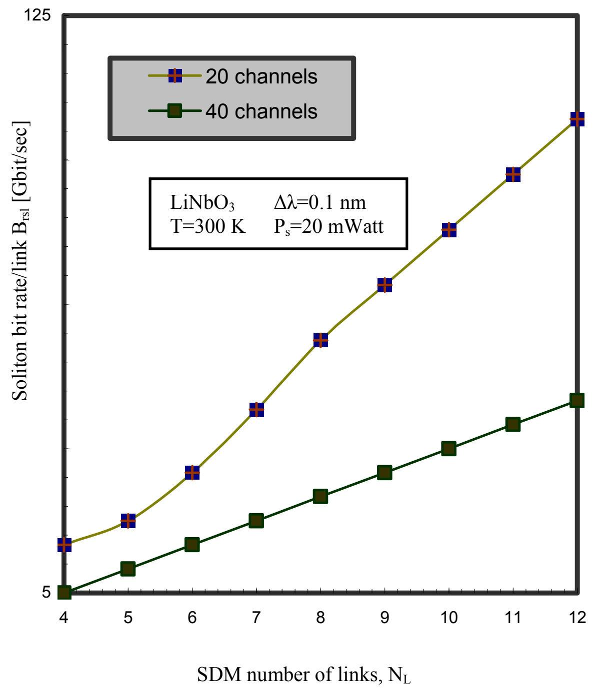

Fig. 9. Variations of soliton bit rate/link against variations of SDM number of links at the assumed set of parameters.

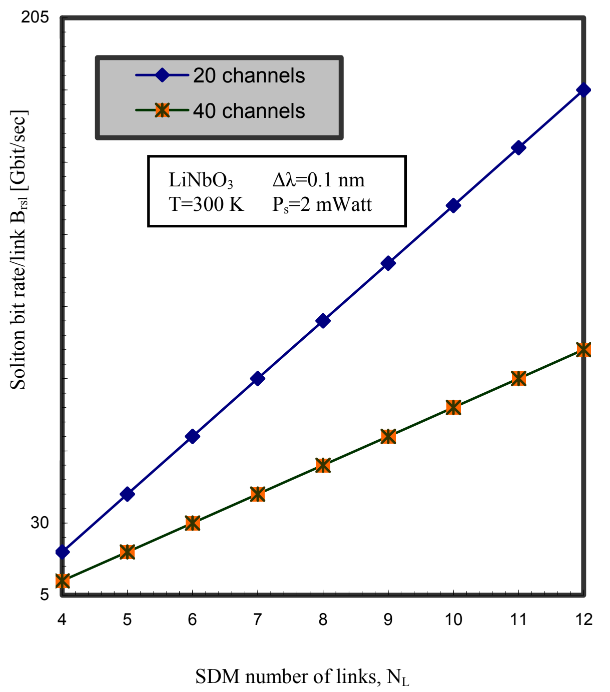

Fig. 8. Variations of soliton bit rate/link against variations of SDM number of links at the assumed set of parameters.

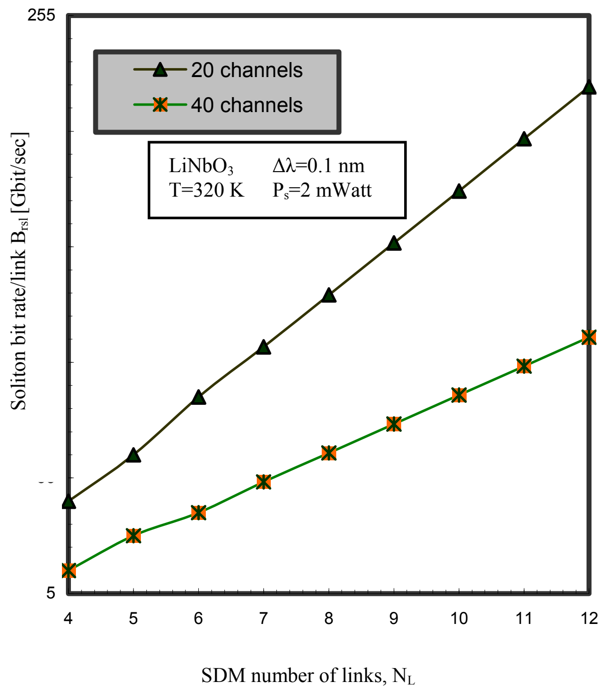

Fig. 10. Variations of soliton bit rate/link against variations of SDM number of links at the assumed set of parameters.

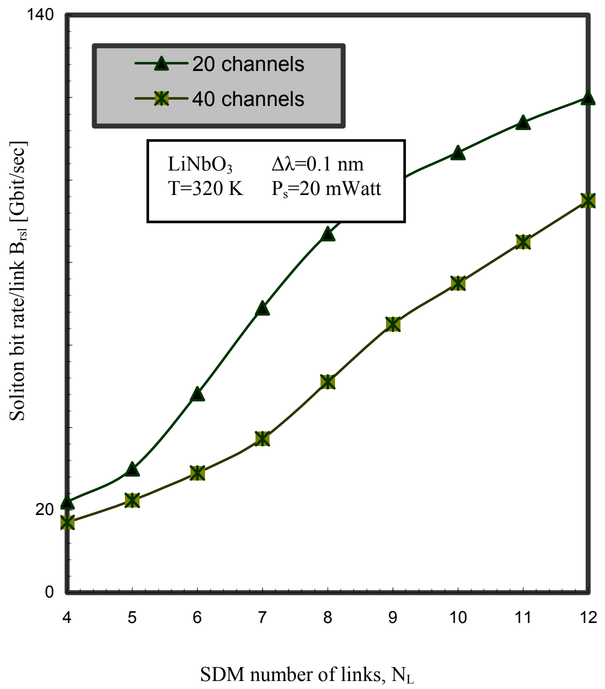

Fig. 11. Variations of soliton bit rate/link against variations of SDM number of links at the assumed set of parameters.

4. Results and General Discussions

In the present study, we investigate the basic Soliton transmission technique to transmit 20-40 channels based on wavelength division multiplexed (WDM), in the interval of 1.45 up to 1.65 µm wavelengths. For the reality from the points of view of the spectral dependences of the different fiber characteristics [14], we employ also the space division multiplexing (SDM) where 20-40 channels are divided into subgroups each subgroup has its own spectral characteristics as in Fig. 2. With N_L= {4, 5, 6,7,……………….12 } Links.

Figure (3) shows the wavelength map in the interval of 1.45 µm-1.65 µm. $\delta\lambda_s$, channel spacing = $\Delta\lambda_s/N_{ct}$, µm

where: $\Delta\lambda_L = \Delta\lambda / N_L \equiv Link\ spacing$ (12)

$$\delta\lambda_s = \Delta\lambda / (N_{ch} * N_L) = \Delta\lambda_L / N_{ch} \quad (13)$$

$$|\delta f| = \delta\lambda / \lambda_{ave}^2 * C \quad (14)$$

$$|\Delta f| = \{\Delta\lambda_L / N_{ch} * \lambda_{ave}^2\} * C \quad (15)$$

where: C=3x10^8 m/sec , N_{ch} ≡ Number of channels/link, N_L ≡ Total number of links/core, N_{ct} ≡ Total number of channels = 20 or 40 channels. Where Δn= $\Delta n_f - \Delta n_i$ = 4.5 – 1.5 = 3.0, and Δλ = $\lambda_f - \lambda_i$ = 1.65 – 1.45 = 0.20 µm.

$$\lambda_s(initial)/link = 1.45 + (JS-1)\delta\lambda_s \quad (16)$$

with JS ={1 , 2 , 3 …………………… N_L}.

where the suffix "f" denotes the final value and "i" denotes the initial value, λ_{ave} is the average wavelength over the link of order JS, JS is the order of the link where 1 ≤ JS ≤ N_L, N_L is the total number of links, λ_{si} is the initial wavelength at the link JS, and λ_{sf} is the final wavelength at the link JS. Due to the nonlinear limitations [15], so that the signal power P_{so} must satisfies the inequality: i.e. ,

$$P_{so}\delta f \le 500 / N_{ch}^2 \quad \text{watt. GHz} \quad (17)$$

Also, the optical wavelength span 1.45 ≤ λ, µm ≤ 1.65 is divided into intervals equal

$$\Delta\lambda_0 = 0.2 / N_L, \ \mu m/Link. \quad (18)$$

The average optical wavelength λ_{ave} over a link of order JS is:

$$\lambda_{ave} = 0.5\Delta\lambda_0 (JS+1) \ , \quad (19)$$

At the set of controlling parameters in Figs. (4–11):
1.45 ≤ λ_s, optical wavelength, µm ≤ 1.65, N_{ct}, total number of channels= 20 or 40 channels, 4 ≤ N_L, number of links ≤ 12 , 1.5 ≤ Δn, relative refractive index difference ≤ 4.5,
4 ≤ N_L, number of links ≤ 12, 300 K ≤ Temperature, T ≤ 320 K, 2 mWatt ≤ P_s, signal power ≤ 20 mWatt, and Δλ = 0.1 nm.

Variations of both Soliton bit rate/channel, and Soliton bit rate/link against variations of the affecting parameters are displayed in Figs. (4-11):

(1) The increased optical wavelength (λ) yielding higher bit rates, but as the temperature increases, this results in decreasing bit rates at the same signal power.
(2) The increased optical wavelength (λ) yielding higher bit rates, but as signal power increases this results in increasing bit rates at the same temperature.
(3) The increased SDM number of links yielding increased in Soliton bit rates/link for minimum number of channels and increased signal power.
(4) Soliton bit rate/channel is increased for minimum number of channels, decreased temperature and increased signal power.

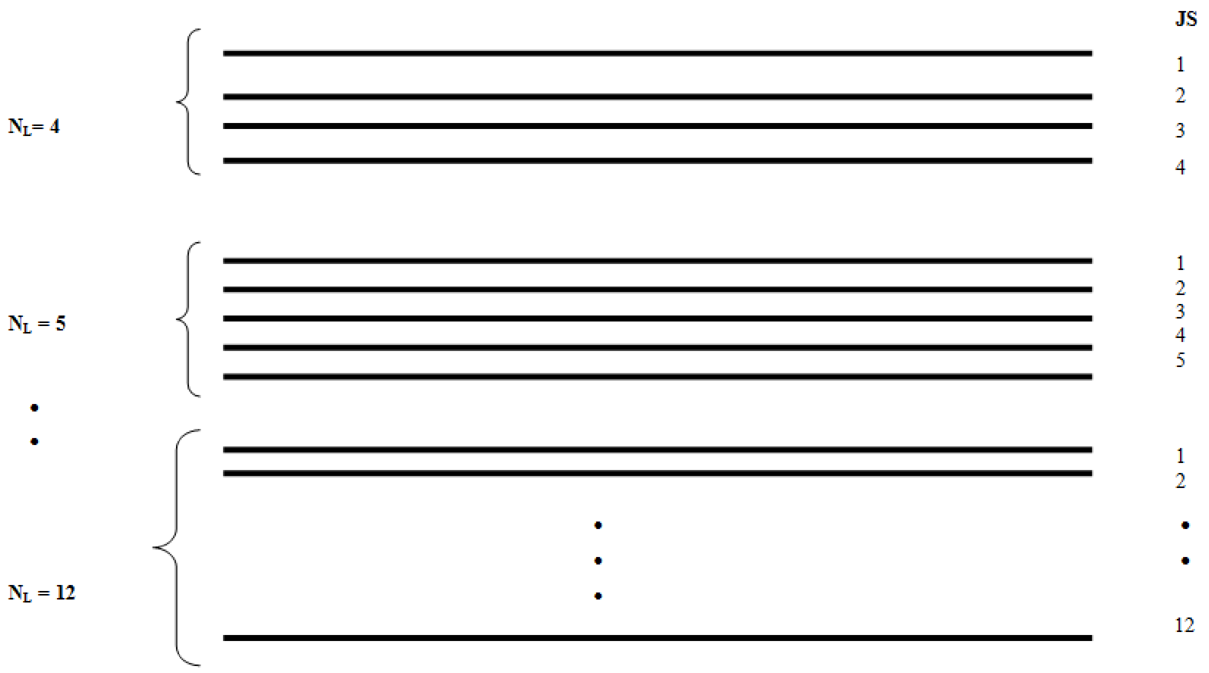

Fig. 2. The Links Map.

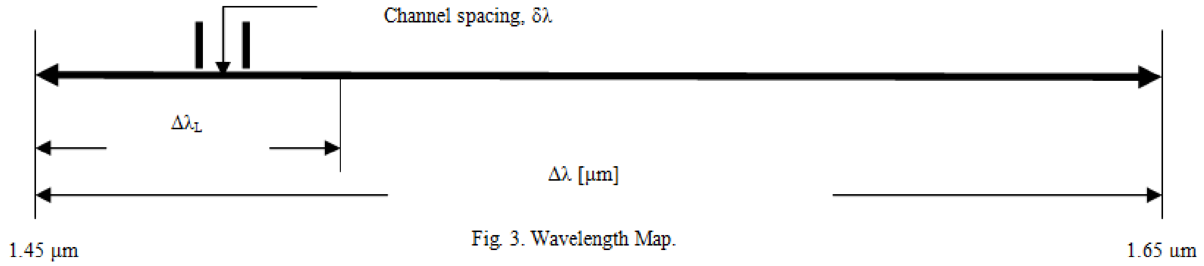

Fig. 3. Wavelength Map.

5. Conclusions

1.1 In a summary, we have presented the investigation of the basic Soliton transmission technique to transmit 20-40 channels based on wavelength division multiplexed (WDM), in the interval of 1.45 up to 1.65 μm wavelengths. Two multiplexing methods are applied, Space Division Multiplexing (SDM) and Wavelength Division Multiplexing (WDM), where 20-40 channels are processed to handle the bit rate either per channel or per link for planar arrayed waveguide cables of multi-links (4-12 links/core). The increased optical signal wavelength, the higher bit rates either per link or per channel at the decreased temperature and increased signal power.

References

[1] M. K. Smit, "PHASAR-based WDM-Devices: Principles, Design, and Applications," IEEE J. Select. Topics Quantum Electron., Vol. 2, pp. 236–250, June 1996.

[2] K. Okamoto and H. Yamada, "Arrayed-Waveguide Grating Multiplexer With Flat Spectral Response," Opt. Lett., Vol. 20, pp. 43–45, 1995.

[3] C. Dragone, "Efficient Techniques for Widening the Passband of A wavelength Router," J. Lightwave Technol., Vol. 16, pp. 1895–1906, Oct. 1998.

[4] D. F. Grosz, A. Agarwal, S. Banerjee, A. P. Kung, D. N. Maywar, A. Gurevich, T. H. Wood, C. R. Lima, B. Faer, J. Black, and C. Hwu, "5.12 Tb/s Transmission With 0.8 bit/s/Hz Spectral Efficiency Over 1280 km of Standard Single-Mode Fiber Using All-Raman Amplification and Strong Signal Filtering," Proc. European Conference on Optical Communication, PD Paper 4.3, 2002.

[5] C. Rasmussen, S. Dey, J. Bennike, B. Mikkelsen, P. Mamyshev, M. Kimmitt, and V. Ivshin, "Transmission of 40 Gbit/s Over 5200 km Ultra Wave® Fiber With

Terrestrial 100 km Spans Using Turn-Key ETDM Transmitter and Receiver," Proc. European Conference on Optical Communication, PD Paper 4.4, 2002.
[6] H. Uetsuka, "AWG Technologies for Dense WDM Applications," IEEE Quantum Electronics, Vol. 10, No. 2, pp. 393-402, March/April 2004.
[7] O. M. Matos, M. L. Calvo, P. Cheben, S. Janz, and A. Delage, "Arrayed Waveguide Grating Based on Group Index Modification," Journal of Lightwave Technology, Vol. 24, No. 3, pp. 1551-1559, Mar. 2006.
[8] M. Simmons, "Survivable Passive Optical Networks Based on Arrayed Waveguide Grating Architectures," Journal of lightwave Technology, Vol. 25, No. 12, pp. 3658-3669, Dec. 2007.
[9] D. H. Jundt, "Fabrication Techniques of Lithium Niobate Waveguides," Optics Letters, Vol. 22, No. 9, pp. 1553-1559, 1997.
[10] G. Keiser, Optical Fiber Communications, Me Graw-Hill, Ch. 3, USA, 2000.
[11] George I. A. Stegeman, Demetrios N. Christodulides, and Mordeechai Segev, "Optical Spatial Solitons: Historical Perspective," IEEE J. on Selected Topics in Quantum Electronics, Vol. 6, No. 6, pp. 1419, Nov./Dec. 2000.
[12] E. Desurivire, Erbium-Doped Fiber Amplifiers: Principles and Applications, JW& Sons, Inc., NY, 1994.
[13] R. T. Sanderson, Inorganic Chemistry, East-West Press PVT, LTD, New Delhi, India 1979.
[14] A. R. Chraplyvy, " Limitation on Lightwave Communication Systems Imposed by Optical Fiber Nonlinearities, "J. Lightwave Technol., Vol. 18, No.10, pp. 1548-1557, Oct., 1990.
[15] T. Otani, T. Miyazaki, S. H.. Carassa, and S. Yamamot, "40-Gb/sec Optical 3R Regenerator Using Electro Absorption Modulators for Optical Communication Networks, " J. Lightwave Technol., Vol. 20, No. 2, pp. 195-200, Feb., 2002.

Ahmed Nabih Zaki Rashed was born in Menouf, Egypt, in 1976. Received the B.Sc. and M.Sc. degrees in Electronics and Electrical Communication engineering from faculty of Electronic Engineering, Menoufia University in 1999 and 2005, respectively. Currently, my field interest and working toward the Ph.D degree in Passive Optical Networks (PONs) and my field experencience in optical communication networks.