Performance Analysis of WDM-PON FTTH Using Different Pulse Shapes at 10 Gbps and 20 Gbps

A. Elrashidi[1,4], I. Ashry[2,4], A. Mahros[3,4], M. Alhaddad, and K. Elleithy

***Abstract*— In this paper, we introduce a full fiber-to-the-home system architecture. The introduced system is used to obtain a system bit rate of 10 Gbps and 20 Gbps downstream and 5 Gbps and 10 Gbps upstream. Wavelength division multiplexing passive optical network technique is used to share the overall bandwidth between 32 users with 0.8 nm spacing between each user. To reduce the overall cost of the proposed system, the bidirectional subcarrier multiplexed technique is used at the optical network unit to avoid using any optical laser sources at the receiver side for upstream data transmission. Quality factor, bit error rate, and eye diagrams are derived for different pulse shapes then used to compare the results in order to select the best pulse shape that gives the best performance. The pulse shapes used in this paper are non-return to zero, return to zero, saw-up, triangle, raised cosine, and hyperbolic-secant pulses. The results demonstrates that the non-return to zero pulse shape at bit rate of 20 Gbps at both downstream and upstream data transmission leads a high quality factor. Furthermore, at 10 Gbps return to zero is selected at the transmission side and hyperbolic-secant at the optical network unit.**

***Index Terms*—Fiber-to-the-home, WDM-PON, SCM, RSOA, Bit error rate, Quality factor, Eye diagram, Central office, Optical network unit, RZ, NRZ, Raised cosine, Hyperbolic-secant, Triangle, and Saw-up pulse shape.**

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[1]A. Elrashidi is with the Department of Electronics and Communications Engineering, College of Engineering and Information Technology, University of Business and Technology, Jeddah 21432, Saudi Arabia (phone: +966-561-127894; e-mail: a.elrashidi@ubt.edu.sa).

[2]I. Ashry is with the Department of Electronics and Communications Engineering, College of Engineering and Information Technology, University of Business and Technology, Jeddah 21432, Saudi Arabia (e-mail: i.ashry@ubt.edu.sa).

[3]A. Mahros is with the Department of Physics, King Abdulaziz University, Jeddah 21432, Saudi Arabia (amr.mahros@mena.vt.edu)

[4]Department of Engineering Mathematics and Physics, Alexandria University, Alexandria 21544, Egypt.

M. Alhaddad is with the Department of Electrical Engineering, College of Engineering and Information Technology, University of Business and Technology, Jeddah 21432, Saudi Arabia (e-mail: mmhaddad@cba.edu.sa).

K. Elleithy is with the Department of Computer and Electrical Engineering, Faculty of Engineering, University of Bridgeport, CT 06604, USA (e-mail: elleithy@bridgeport.edu).

I. INTRODUCTION

The explosive growth of the Internet is the main reason to introduce a broadband access network based on Fiber-to-the-Home (FTTH). Some applications such as streaming Internet video, video-on-demand, and cloud-based storage require high bandwidth [1]. Traditional single wavelength passive optical network (PON) using time division multiplexing (TDM) suffers from some problems such as [2];

1. The optical carrier is shared by means of passive splitter among all users.
2. The number of optical network units (ONUs) is limited which leads to power-splitter losses values in the range 16-17 dB for 1×32 splitter.
3. Bandwidth sharing (10G-EPON).
4. Bit rate transparency is about 10 Gbps.
5. High-speed TDM-PON requires high-rate burst-mode circuits.

So, the wavelength division multiplexed WDM-PONs are expected to provide more capacity and flexibility to meet the needs of higher bit rate delivered to each user (1 Gbps for downstream and 0.5 Gbps for upstream). WDM-PON has many advantages over TDM/TDMA-PON such as [3];

1. Bandwidth is available for all users (bit rate transparency is unlimited).
2. Splitting loss is 3-5 dB (WDM filter loss).
3. There is no burst mode.
4. It is easy to implement fault localization (optical time domain reflectometer).
5. It is scalable which implies that you can expand the installed equipment for additional demand as needed.
6. It is possible to upgrade the capacity of the existing fiber networks (without adding fibers).

For these reasons WDM-PON is considered as a primary solution for NG-PONs with 40 Gbps downstream and 10 Gbps upstream and 32 users for 15-20 km distance. On the other hand, some design issues should be considered when WDM is used in PONs system. The compatibility of WDM-PON with existing TDM-PON is a major requirement for NG-PON to be economically viable [4]. Single feeder architecture should be maintained in the system and arrayed waveguide grating (AWGs) would replace the passive power splitters at the remote node (RN). Also, colorless optical network unit is very urgent to eliminate redundancy for the network operator [5]. In designing WDM-PON system, three parameters should be

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considered which are bit rate, fiber length, and the transmitted power.

In this paper, we introduce a full design of a WDM-PON system using 32 channels for 20 km length using different pulse shapes. The used pulses are non-return to zero, return to zero, saw-up, triangle, raised cosine, and hyperbolic-secant pulse shapes instead of on-off kenning (OOK). The bidirectional subcarrier multiplexed (SCM) WDM-PON technique is used to reduce the expenses of using a large numbers of laser sources at OMUs [6]. Bit error rate, quality factor, and Eye diagram at 10 and 20 Gbps for transmission and receiving modes are presented using an Optiwave system 7.0 Software.

The paper is organized as follow; in the section II we discuss the technical issues for WDM-PON network system. In section III, we introduce our proposed structure for central office (CO) for downstream and upstream data transmission and receiving, and optical network unit (ONU). In section IV, results and discussion are presented. Section V offers conclusions.

II. Technical Issues in WDM-PON Network System

WDM-PON is considered as an ultimate solution for access network due to its upgradeability, capacity, and its security. Figure 1 shows the transmission bit rate of access networks as a function of time [7].

Although WDM-PON has many advantages, extra costs in the installation of wavelength selected lasers needed in WDM-PON structure represents a fault problem [8]. Some efforts to solve this problem such as using spectrum sliced incoherent light sources or ASE injected Fabry-Peroy lasers are reported in [9]-[10]. The main issue of such solution would be the use of identical light source at every subscriber's site. In this case the use of bidirectional subcarrier multiplexed technique is very efficient to decrease the overall cost of the system. This type of laser source suffers from long tuning time, up to a few seconds [11].

Distributed feedback laser diode (DFB-LD) is a most common tunable laser source using a Bragg gratings technique which etched inside the laser cavity [12]. A thermoelectric cooler (TEC) is required for stable operation for a wavelength shift due to temperature change on the grating.

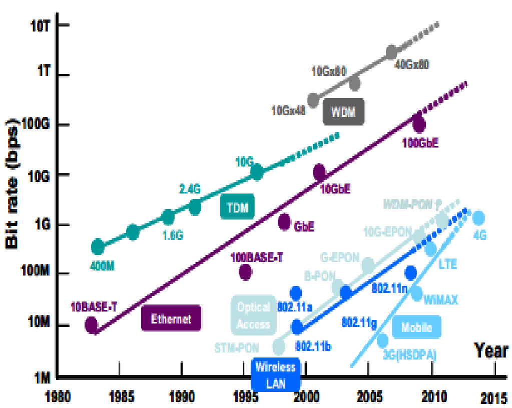

Figure 1. Bit rate of access network as a function of time [7].

Digital signal processing (DSP) is a very efficient solution for increasing bit rate of each user in FTTH. Q. Guo and *et. al.* introduced a 40 Gbps FTTH using modified duobinary coding in the downlink and OOK code in the uplink to improve the tolerance and reduce the crosstalk between uplink and downlink. The authors demonstrated a system with 25 km length, 40 Gbps for the uplink and 10 Gbps for downlink [6]. A DSP based on TDM-OFDM-PON architecture is introduced and experimentally demonstrated as a NG-PON solution by H. Yang and *et. al.* [13].

The architecture performancewhen OFDM symbols is transmitted in different time slots, is compared to the architecture used an OOK. The proposed system shows high performance over distance of 26.7 km and low bit error rate. SCM WDM-PON is experimentally demonstrated by J. Buset and et. al. [2]. Square root raised cosine pulse shape is used to generate an M-ary quadrature amplitude modulation for up and down links using 10 GHz transceiver bandwidth over 20 km single feeder. 2.2 GHz reflective semiconductor optical amplifier on ONU is included with offset optical filter. A. Lebreton and B. Charbonnier introduced an experimental system of 20 Gbps using FDM PON architecture [14]. The authors demonstrate a simulation system of 40 Gbps with RF bandwidth of 12 GHz and roll-off filter of 10 GHz.

III. FTTH Proposed System Architecture

The overall system architecture for CO and ONU is given in this section. Figure 2 illustrates the CO as a transmitter. Distributed feedback laser diode source with 1 mW

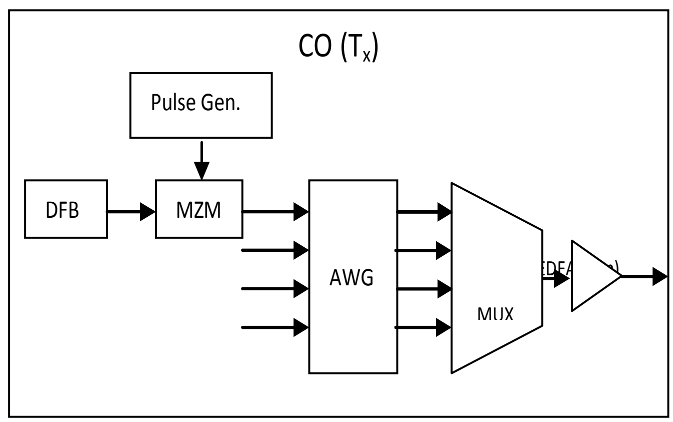

Figure 2. Central office as a transmitter structure.

transmitted power is used. The channel capacity is 32 starting from 1550.12 nm to 1575.37 nm with spacing of 0.8 nm, according to ITU standard [15].

Pulse generator generates different pulses shape such as return to zero (RZ), non-return to zero (NRZ), and triangular shape, and then modulated by Mach-Zehnder (MZM) modulator with extinction ratio of 10 dB. The modulated data is connected to an arrayed waveguide grating (AWG), then to multiplexer and to EDFA amplifier with 5 m length.

The transmitted signal goes through 20 km fiber optics cable before being received by the ONU. Demultiplexer is used before band path filter with bandwidth 0.8 nm for each channel as shown in Figure 3.

Power splitter is then used to split the received power to the photodetector, downstream receiver, and to RSOA to

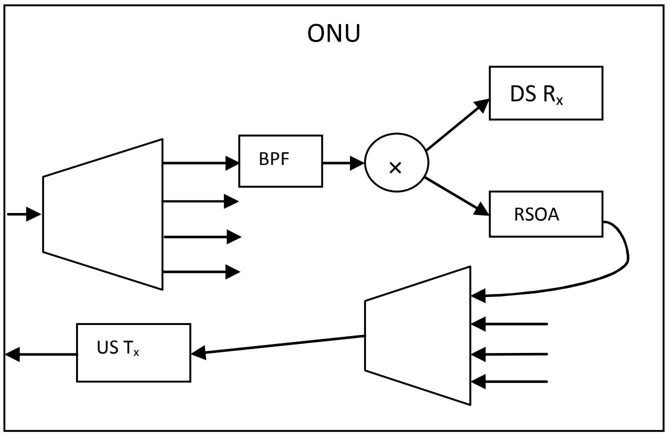

Figure 3. Optical network unit structure.

demodulate the carrier signal with the upstream data.

Input and output coupling loss for RSOA is 1 dB each, and

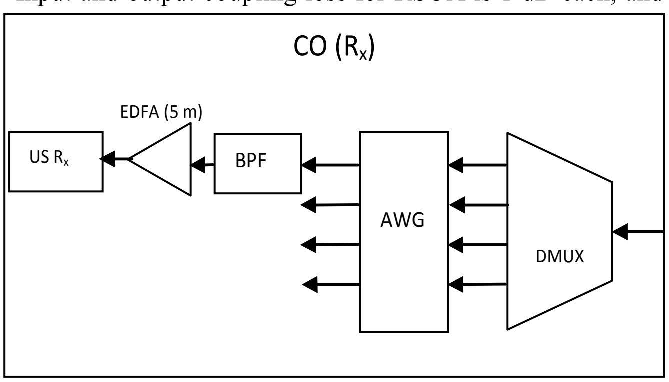

Figure 4. Central office as an upstream receiver structure.

the input and output facet reflectivity is 5×10^{-5} and 0.9 respectively. The output signals are multiplexed and then sent to the US transmitter. The upstream signal transmits through the 20 km fiber and then is received by the CO again as shown in Figure 4. A band path filter is used after AWG with a bandwidth of 0.8 nm, and then an EDFA amplifier with length of 5 m is connected to the amplifier's the received signal.

IV. Results and Discussion

In this section we discuss the quality factor, bit error rate, and the eye diagram for a fiber-to-the-home system at bit rate 10 Gbps and 20 Gbps at CO and ONU using different shapes of pulse modulation techniques. Non-return to zero, return to zero, saw-up, triangle, raised cosine, and hyperbolic-secant pulses modulation techniques are used to compare the results and to select the pulse shape that introduces the best performance for downstream and upstream.

Figure 5 shows the quality factor for different pulse shapes as a function of the bit period at the CO for bit rate 10 Gbps. Return to zero pulse shape gives a quality factor of 691 at low bit period, which is very efficient at the CO.

The quality factors at the transmitter side are shown in Figure 6 for different shapes and at 20 Gbps. Non-return to zero pulse shape gives a maximum quality factor, around 368, and an acceptable bit period.

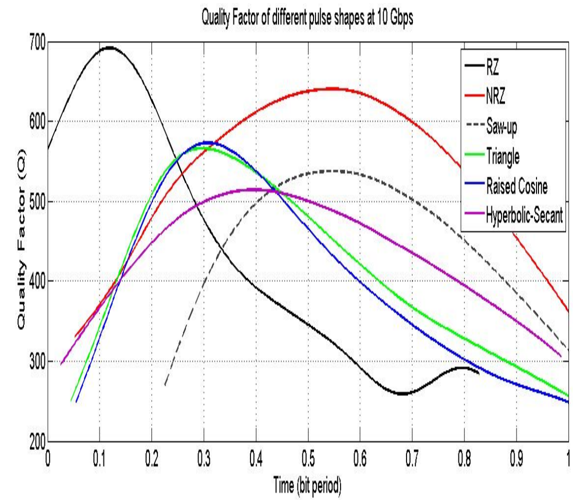

Figure 5. Quality factor for different pulse shapes at 10 Gbps at the transmission side.

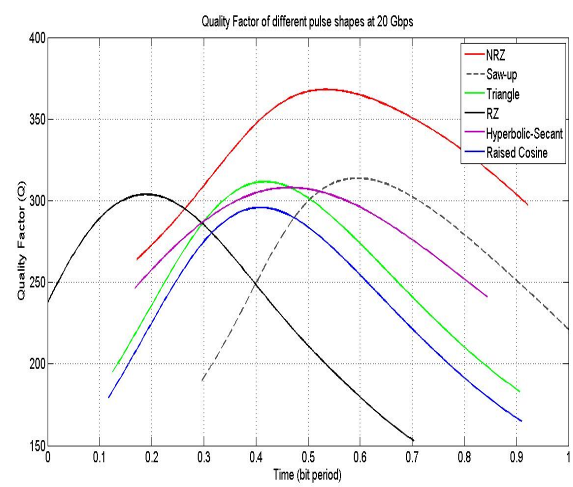

Figure 6. Quality factor for different pulse shapes at 20 Gbps at the transmission side.

At OUNs, the quality factors for different pulse shapes at 10 and 20 Gbps bit rates are illustrated in Table 1. Hyperbolic-secant pulse shape gives the best value for the quality factor, 860, while the non-return to zero gives the best quality factor at 20 Gbps, 121.

Eye diagrams give illustrates the performance of any downstream or upstream rates. Figure 7 shows the eye diagram of return to zero pulse shape at the CO at bit rate of 10 Gbps. The difference between the maximum and the minimum is 7 ma.u. and is of uniform shape, which gives a good indication of bit rate and quality factor.

TABLE 1
QUALITY FACTOR FOR DIFFERENT PULSE SHAPES AT 10 AND 20 GBPS AT THE ONU SIDE.

Pulse shape	Quality Factor

	US (10 Gbps)	US (20 Gbps)
NRZ	206	121
RZ	680	112
Saw-up	755	102.8
Triangle	783	105.6
Raised Cosine	776	111.7
Hyperbolic-Secant	860	118.6

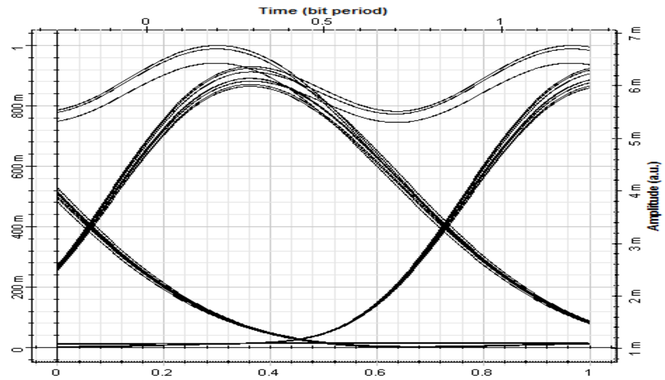

Figure 7. Eye diagram of return to zero at the transmission side at 10 Gbps.

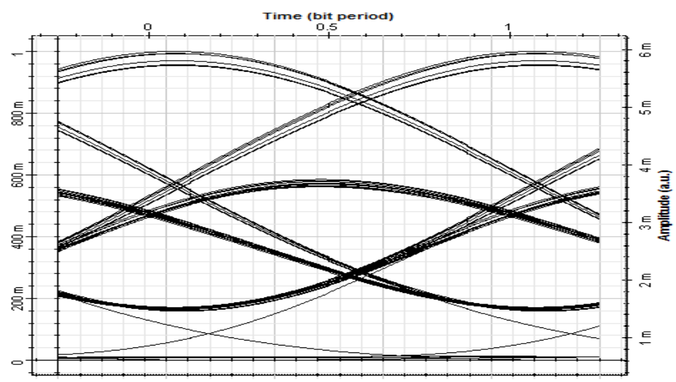

Figure 8. Eye diagram of non-return to zero at the transmission side at 20 Gbps.

The eye diagram of non-return to zero pulse shape at the CO at bit rate of 20 Gbps is shown in Figure 8. The difference between the maximum and the minimum is 6 ma.u. At the ONUs, the eye diagram for hyperbolic-secant pulse shape is illustrated in Figure 9. Figure 10 shows the eye diagram for non-return to zero pulse shape at the ONU and 20 Gbps.

The bit error rate for different pulse shapes at both CO and ONU for 10 and 20 Gbps bit rate are illustrated in Table 2. The minimum bit error rate at the CO at 10 Gbps is 0.97×10^{-5} for non-return zero and is 1.05×10^{-5} for non-return to zero pulse also at the ONUs. At bit rate 20 Gbps, the bit error rate at the CO is 1.01×10^{-3} for return to zero pulse and 2.00×10^{-3} for saw-up pulse shape at the ONU.

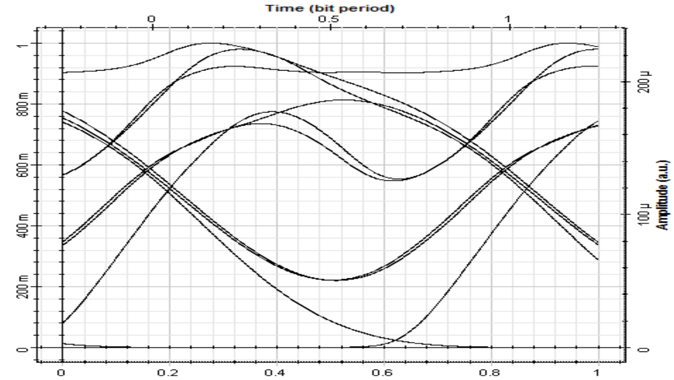

Figure 9. Eye diagram of hyperbolic-secant at the receiver side at 10 Gbps.

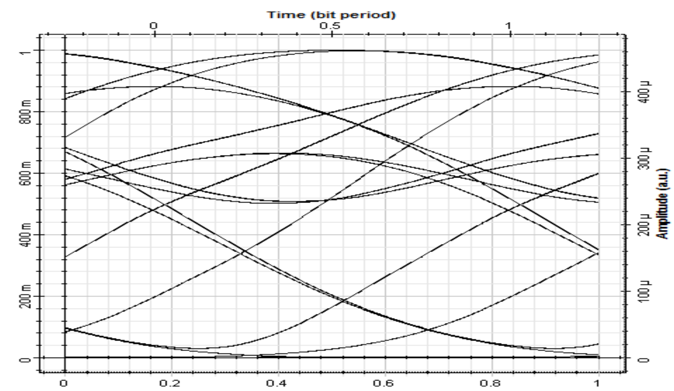

Figure 10. Eye diagram of non-return to zero at the receiver side at 20 Gbps.

TABLE 2
BIT ERROR RATE FOR DIFFERENT PULSE SHAPES AT 10 AND 20 GBPS AT THE CO AND ONU SIDES.

Pulse shape	BER at 10 Gbps (10^{-5})		BER at 20 Gbps (10^{-3})	
	DS	US	DS	US
NRZ	0.97	1.05	5.60	3.07
RZ	1.34	1.40	1.01	2.07
Saw-up	1.20	1.34	1.07	2.00
Triangle	1.24	1.33	1.10	2.03
Raised Cosine	1.33	1.45	1.09	2.09
Hyperbolic-Secant	2.35	1.69	1.55	2.77

V. CONCLUSION

A complete Fiber-to-the-Home (FTTH) structure is introduced in this paper. The structure includes CO as transmitter for downstream and receiver for upstream and ONU. The given structure used has a bit rate of 10 Gbps and 20 Gbps for downstream data transmission using a WDM-PON to share the wavelength between 32 users, from 1537.4 nm to 1562.23 nm. Bidirectional SCM technique is used at ONU for data upstream, so there is no need for optical laser sources at the user side for upstream data transmission. Q-factor, BER, and eye diagram are illustrated for different pulse shapes and the results are compared to get the best pulse shape that provides the best Q-factor. Non-return to zero, return to zero, saw-up, triangle, raised cosine, and hyperbolic-secant pulses are used in modulation technique at the CO using MZM and at the ONU side using RSOA. Non-return to zero pulse shape is selected for high Q-factor at bit rate 20 Gbps at both downstream and upstream data transmission. Return to zero is selected for downstream and hyperbolic-secant at the ONU at 10 Gbps.

REFERENCES

[1] K. Tanaka, A. Agata, and Y. Horiuchi, "IEEE 802.3av 10G-EPON standardization and its research and development status," *J. Lightw. Technol.*, vol. 28, no. 4, pp. 651-661, Feb. 15, 2010.

[2] J. Buset, Z. El-Sahn, and D. Plant, "Experimental Demonstration of a 10 Gb/s Subcarrier Multiplexed WDM PON," *IEEE Photo. Technol. Letters*, vol. 25, no. 15, Aug. 1, 2013.

[3] B. Charbonnier, S. Menezo, P. O'Brien, A. Lebreton, J. Fedeli, and B. Bakir, "Silicon Photonics for Next Generation FDM/FDMA PON," *J. Opt. Commun. Netw.,* vol. 4, no. 9, Sept. 2012.

[4] F. Bourgart, " NGPON2- Where are the Standards Going?," *National Fiber Optic Engineers Conf.*, Los Angeles, California, USA ,Mar. 4-8, 2012.

[5] K. Roberts, D. Beckett, D. Boertjes, J. Berthold, and C. Laperle, "100G and Beyond with Digital Coherent Signal Processing,"IEEE Commun. Mag., vol. 48, no. 7, pp. 62-69, Jul. 2010.

[6] Q. Guo, and A. Tran, "Demonstration of 40 Gb/s Wavelength Reused WDM-PON Using Coding and Equalization," J. Opt. Commun. Netw., vol. 5, no. 10, Oct. 2013.

[7] K. Iwatsuki, "Application and Technical Issues of WDM-PON," *Proc. SPIE 7620, Broadband Access Commun. Techno*. IV, 76200C, Jan. 22, 2010.

[8] Y. C. Chung, "Challenges Toward Practical WDM PON," *The 11th OptoElec. and Commun. Conf.,* Splendor Kaohsiung, Kaohsiung, Taiwan, 6C4-1-1, Jul. 3-7, 2006.

[9] S. Yoo, J. Kim, B. Seo, M. Kye, and C. Lee, "Mutually Injected Fabry-Perot Laser Diodes for 10-Gb/s Broadcasting in WDM-PON," *18th OptoElec. and Commun. Conf., Kyoto International Con. Center Takaragaike*, Sakyo-ku, Kyoto, Japan, 30 Jun. - 04 Jul. 2013.

[10] Z. Al-Qazwini, and H. Kim, "5-Gb/s Optical Transmitter Based on Incoherent-Light-Injected RSOAs with Graceful Upgrade Capability for WDM PONs," *Opt. Exp.,* vol. 21, Issue 7, pp. 8135-8141, 2013.

[11] T. Kimoto, T. Shinagawa, T. Mukaihara, H. Nasu, S. Tamura, T. Numura, and A. Kasukawa, "Highly Reliable 40-mW 25-GHz×20-ch Thermally Tunable DFB Laser Module, Integrated with Wavelength Monitor," Furukawa Review, no. 24, 2003.

[12] G. Agrawal, Fiber-Optic Communication Systems, Wiley, 2002.

[13] H. Yang, J. Li, B. Lin, Y. Wan, Y. Guo, L. Zhu, L. Li, Y. He, and Z. Chen, "DSP-Based Evolution From Conventional TDM-PON to TDM-OFDM-PON," *J. Lightw. Technol.*, vol. 31, no. 16, pp. 2735-2741, Aug. 15, 2013.

[14] A. Lebreton, and B. Charbonnier, " Toward 40Gbps Downstream FDM PON," *17th Inter. Conf. on Opt. Net. Design and Modeling (ONDM),* Telecom Bretagne, Brest, France, pp. 304-308, Apr. 16-19, 2013.

[15] http://www.oplink.com/pdf/Wavelength.pdf.

Ali M. Elrashidi received the B.Sc. degree in electric engineering from Alexandria University in 2001, the MS Degree in fiber optics from the same university in 2007, and he received Ph.D. degree in Computer Science and Engineering in the University of Bridgeport from 2008-2012. From 2002 to 2008, he was with Physics and Electric Department, Alexandria University, Egypt, as an assistant professor from October 2012 to August 2013 and in University of Business and Technology from August 2013 till now.

Dr. Elrashidi is involved in many research projects in USA, Egypt and Saudi Arabia related to antenna and wave propagations, Fiber-to-the-home, and remote patient monitoring system.

Dr. Elrashidi has research interests are in the areas of electromagnetics and wave propagation, mobile communications, optical fiber communication, and hardware design in a nanoscale. He has more than eleven years of teaching experience. From 2002-2013 he has taught solid state physics, physics, fiber optics, solid state electronics, modern physics, fiber optics, solid state electronics, electrical measurements, introduction to communications, electronics II, and antenna systems courses.

Khaled M. Elleithy received the B.Sc. degree in computer science and automatic control from Alexandria University in 1983, the MS Degree in computer networks from the same university in 1986, and the MS and Ph.D. degrees in computer science from The Center for Advanced Computer Studies at the University of Louisiana at Lafayette in 1988 and 1990, respectively

Currently, Dr. Khaled Elleithy is the Associate Dean for Graduate Studies in the School of Engineering at the University of Bridgeport. He has research interests are in the areas of network security, mobile communications, and formal approaches for design and verification. He has published more than two hundreds research papers in international journals and conferences in his areas of expertise.

Dr. Elleithy is the co-chair of the International Joint Conferences on Computer, Information, and Systems Sciences, and Engineering (CISSE). CISSE is the first Engineering/Computing and Systems Research E-Conference in the world to be completely conducted online in real-time via the internet and was successfully running for six years. Dr. Elleithy is the editor or co-editor of 12 books published by Springer for advances on Innovations and Advanced Techniques in Systems, Computing Sciences and Software.