Australian Journal of Basic and Applied Sciences, 3(2): 1489-1498, 2009
ISSN 1991-8178

Design of Low Cost Encoder for Optical Code Division Multiple Access (OCDMA) Using Arrayed Waveguide Gratings (AWGs) and Optical Switches

Mohammad Syuhaimi Ab-Rahman, BoonChuan Ng, Norshilawati Mohamad Ibrahim
Spectnm Technolgy Division,

[1]Computer and Network Security Research Group Department of Electrical, Electronics and Systems Engineering Faculty of Engineering and Built Environment Universiti Kebangsaan Malaysia 43600 UKM Bangi, Selangor, Malaysia

Abstract: This paper describes the development of a 16-port optical code division multiple access (OCDMA) encoder prototype based on Arrayed Waveguide Grating (AWG) and optical switches. The encoder is one of the new technologies that used to transmit the coded data in the optical communication system by using AWG and optical switches. It provided a high security for data transmission due to all data will be transmitted in binary code form. The output signals from AWG are coded with a binary code that given to an optical switch before it signal modulate with the carrier and transmitted to the receiver. The 16-ports encoder used 16 double pole double throw (DPDT) toggle switches to control the polarization of voltage source from +5 V to -5 V for 16 optical switches. When +5 V is given, the optical switch will give code '1' and vice versa. The experimental results showed the insertion loss, crosstalk, uniformity, and optical signal-noise-ratio (OSNR) for the developed prototype are <12 dB, 9.77 dB, <1.63dB, and ≥20 dB.

Key Words: OCDMA, encoder, AWG, optical switch, DPDT toggle switches.

INTRODUCTION

Since the Internet and broad-band access network were introduced during the last decade, emerging applications, such as video on demand (VoD), digital cinema, telepresence, and high-quality audio transmission, demand high-throughput optical access networks with stringent quality of service (QoS) requirements. However, the infrastructure of current access networks suffers from limited bandwidth, high network management cost, low assembly flexibility, and bad network security, which obstructs the network from delivering integrated services to users. Owing to the maturity of optical components and electronic circuits, optical fiber links have become practical for access networks (Zhang *et al.,* 2006). Passive optical network (PON) based on some multiplexing technologies, including time division multiplexing (TDM), wavelength division multiplexing (WDM), hybrid TDM/WDM, code division multiplexing (CDM), and optical code division multiplexing (OCDM) for access networks have been proposed.

PON is one of the most promising solutions for fiber-to-the-office (FTTO), fiber-to-the-home (FTTH), fiber-to-the-business (FTTB), and fiber-to-the-curb (FTTC), since it breaks through the economic barrier of traditional point-to-point (P2P) solutions. PON has been standardized for FTTH solutions and is currently being deployed in the field by network service providers worldwide. Even though time division multiple (TDM)-PON utilizes effectively the bandwidth of fiber, it has limitations in its increased transmission speed, difficulty in burst synchronization, low security, dynamic bandwidth allocation (DBA) requirement and inaccurate Ranging (Ohara, 2003; Aiss *et al.,* 2003; Iwatsuki *et al.,* 2004).

Interest in OCDMA has been steadily growing during recent decades (Fathallah, 2006). That trend is accelerating due to fiber penetration in the first mile and the establishment of PON technology as a pragmatic solution for residential access Koonen (2006). OCDMA is one promising technique for next-generation broadband access network with the following advantages: asynchronous access capability, accurate time of arrival measurements, flexibility of user allocation, ability to support variable bit rate, busty traffic and security against unauthorized users. OCDMA is a very attractive multi-access technique that can be used for local area

Corresponding Author: Mohammad Syuhaimi Ab-Rahman, Spectnm Technolgy Division, Computer and Network Security Research Group, Department of Electrical, Electronics and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia Tel.: +603-89216448; Fax: +603-89216146
E-mail: syuhaimi@vlsi.eng.ukm.my, ngbc@vlsi.eng.ukm.my

network (LAN) and the first one mile (Salehi, 1989). Moreover, the OCDMA method is preferable for multiplexing in the optical domain because it uses broad bandwidths in optical devices for the electrical CDMA method and the electrical-to-optical (E/O) conversion (Park, *et al.,* 2004).

OCDM is a multiplexing procedure by which each communication channel is distinguished by a specific optical code rather than a wavelength or time-slot. An encoding operation optically transforms each data bit before transmission. At the receiver, the reverse decoding operation is required to recover the original data. The encoding and decoding operations alone constitute optical coding. OCDMA is the use of OCDM technology to arbitrate channel access among multiple network nodes in a distributed fashion (Fouli and Maier, 2007).

There are many different kinds of OCDMA encoder/decoders use optical delay lines or optical switches with optical orthogonal code (OOC) for the time domain; fiber Bragg grating (FBG) or AWGs and OOCs for the optical frequency domain, and FBGs or AWGs for optical wavelength-hopping / time spreading (TS) (Park, *et al.,* 2004).. AWG-based encoder/decoder has the unique capability of simultaneously processing multiple time-spreading optical codes (OCs) with single device, which makes it a potential cost-effective device to be used in the central office of OCDMA network to reduce the number of encoder/decoders. The AWG-based encoder/decoder also has very high power contrast ratio (PCR) (15~20 dB) between auto- and cross-correlation signals, which means the interference value could be significantly reduced (up to 20 dB) with the short OC (Wang *et al.,* 2007).

AWG-based OCDMA encoder prototype:

The 16-ports AWG-based OCDMA encoder prototype is consists of 1 input port and 16 output ports for AWG demultiplexer (demux) and multiplexer (mux) with back-to-back (serial) connection, as shown in Fig. 1 and 2. An adaptor device is used to convert the alternating current (AC) from the power supply to direct current (DC) and reduce the power supply from 240 V AC to 12 V DC. In the circuit design, a 12 V battery is used to replace the adaptor device. Due to the optical switch only function with a maximum input voltage at 5 V, a voltage regulator circuit is designed to reduce the voltage output from adaptor device (12 V) to 5 V for 16 different optical switches as indicated in Fig. 3.

The encoder is using 16 DPDT toggle switches to control the polarization of voltage source for 16 different optical switches. The optical switch will automatically change (opposite) the polarization of voltage source from +5 V to -5 V. Output voltage (5 V) from voltage regulator circuit is distributed to 16 different DPDT switches evenly to activate 16 optical switches. The output voltage is 5 V when the switch 1 in Fig. 3 is push up, and alters to -5 V when the switch 2 is push down.

Each optical switch is connected to an input and two output representation links (Link 1 and 2). There are 8 pins of the optical switch responsible for controlling the polarization of voltage source. Among that, pin 1 and pin 8 are controlling the optical path exchange. When -5 V is provided to the optical switch, the input link is connected to link 1. On the other hand, the input link is connected to link 2 if +5 V is provided to the optical switch. The parameters of optical switch such energy switching, dissipation insertion, reflection losses, crosstalk, and switching time, play an important role in the optical switching.

Fig. 1: Photographic view of 16-ports AWGs with back-to-back

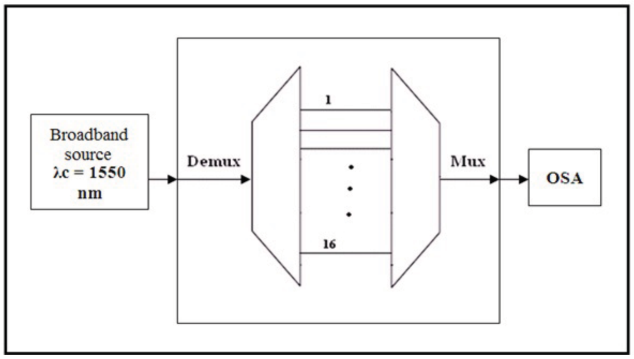

Fig. 2: Block diagram of linearity test for AWG with back-to-back connection.

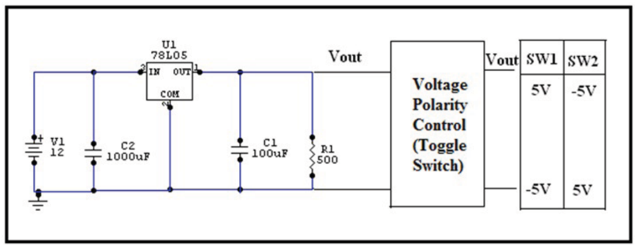

Fig. 3: The voltage regulator circuit and voltage polarity control.

Characteristics of AWG-based OCDMA encoder:

Two methods are being used to study the specifications of the 16-ports AWG-based OCDMA encoder: linearity test and continuous signal test.

Linearity Test:

The linearity adjustment among two AWGs should proceed in designing an OCDMA encoder to assess counter their linearity's impact, although both AWGs' specifications are similar. The linearity test is conducted to compare the waveforms between the transmission signals and receiving signals according to their specifications before characterizing the encoder. This test is important for identifying a failure or damaged AWG. The broadband laser source with mean wavelength 1550 nm is supply to 16-ports demux and 16-ports mux before connected to analyze the spectrums in optical spectrum analyzer (OSA) (see Fig. 2).

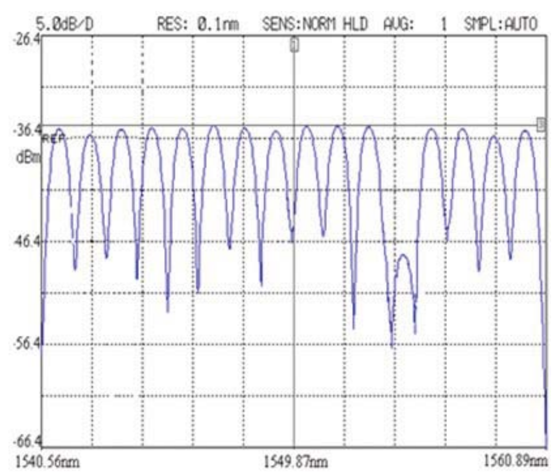

Fig. 4: The spectrum display for AWG back-to-back connection.

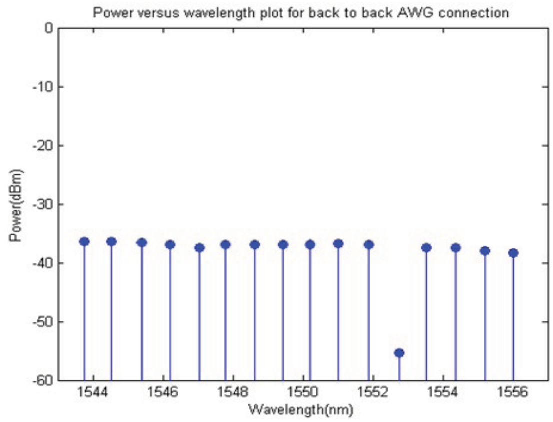

Fig. 5: Power vs. wavelength plot for AWG back-to-back connection.

Table 1. Mean wavelength, peak power, and different, λ_c for AWGs with back-to-back connection.

Ports	λ_c (nm)	Peak Power (dBm)
1	1543.760	-36.40
2	1544.540	-36.40
3	1545.370	-36.70
4	1546.200	-36.90
5	1547.040	-37.40
6	1547.800	-36.90
7	1548.620	-36.89
8	1549.420	-36.87
9	1550.220	-36.87
10	1551.020	-36.80
11	1551.900	-36.90
12	1552.750	-55.40
13	1553.520	-37.50
14	1554.360	-37.50
15	1555.200	-37.94
16	1556.000	-38.40

Continuous Signal Test:

The parameters of the OCDMA encoder such as insertion loss, optical signal-noise-ratio (OSNR), uniformity, and crosstalk are measured through a continuous signal test to increase service reliability and efficiency of coding to make sure any information or data are correctly delivered. The instruments and measurement equipments such broadband source, tunable light source (TLS), and OSA are used in the experiment as summarized in Fig. 6 with the help of the block diagram. The output signals from demux port are coded in binary form, either '1' or '0'. When +5 V is given, the optical switch will give ‘1’ and ‘0’ is given to -5 V. The coding is based on the voltage polarity control of voltage regulator circuit. All the output signals will be combined by mux and then analyzed in OSA to observe the spectrums’ specifications.

Each optical switch has 2 delay ports and each port is connected to an optical fiber line with specified range. The wavelengths from demux will be modulated with the binary code '1’ in optic switches when voltage supply + 5 V are given. Then, the signals will move to the delay port (from port D1 to port D2) and returned to mux to deciphered and analyze in OSA. However, when voltage supply - 5 V are given, the signals still move to the delay port even though they don’t modulate with the binary code. The characterization will be carried out based on the coding. Each output signals from demux are given a different binary code and analyzed in OSA. The parameters of uniformity and crosstalk can be identifying through the spectrums display. Fig. 7 shows the spectrum display for 8-channels OCDMA encoder in OSA when broadband source is given with the binary code 11111111. Table 2 shows the mean wavelength and peak power of pass band for 8-channel OCDMA encoder.

Uniformity:

Three parameters of the AWG-based OCDMA encoder: uniformity, crosstalk, and insertion loss (IL), are measured in this test. Uniformity is the different values of optical power between the maximum peak power, P1, and minimum peak power, P2. The uniformity measurement for 8-ports AWG-based OCDMA encoder is shown in Fig. 8, where:

$$\text{Uniformity} = \text{Maximum peak power, P1} - \text{Minimum peak power, P2} \qquad (1)$$

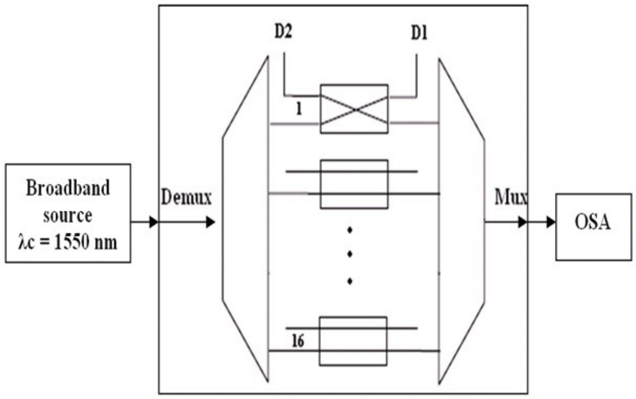

Fig. 6: Block diagram of continuous signal testing for OCDMA encoder

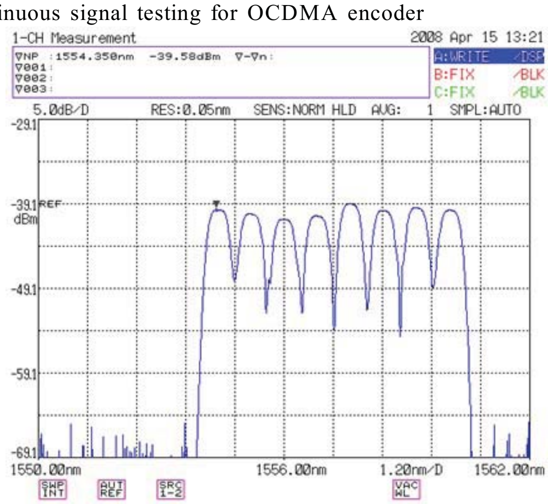

Fig. 7: Spectrum display for 8-channels OCDMA encoder.

Table 2. Mean wavelength and peak power of pass band for 8-channel OCDMA encoder.

	λc (nm)		Pass band		
Ports	Spec.	Measurement	3 dB	10 dB	Peak Power (dBm)
9	1544.94	1544.32	0.60	0.76	-37.69
10	1555.75	1555.13	0.56	0.76	-38.51
11	1556.56	1556.01	0.56	0.76	-38.91
12	1557.36	1556.79	0.60	0.76	-38.5
13	1558.17	1557.57	0.60	0.80	-37.28
14	1558.98	1558.41	0.56	0.80	-38.06
15	1559.79	1559.21	0.56	0.80	-37.77
16	1560.61	1559.99	0.56	0.80	-38.20

Crosstalk:

Crosstalk is measured the degree of isolation between the input at one port and the optical power scattered or reflected back into the other input port (see Fig. 9).

Insertion Loss:

The insertion loss refers to the loss for a particular port-to-port path. The value of wavelength for each port is acquired from the broadband source admitted into TLS source with input power 0 dB and the output power is listed in Table 2. The output power is the value for insertion loss. Theoretically, the insertion loss is measured for each device is used in testing. The loss for each optical switch is 1.2 dB and the patch cord cable absorbed 0.3 dB for each 3m. The connector loss is very small and can be neglected. The total losses:

$$\text{Total Loss} = [(1.2 \times 8) + (0.3 \times 2) + (5.0 \times 2)]\ \text{dB} = 20.2\ \text{dB} \tag{2}$$

The calculation for insertion loss is much more higher as compared to the experimental value. The Insertion loss vs. output ports plot is indicated in Fig. 10. From the graph, we found that the dissipation for on port 11 is highest and the port 13 is lowest due to the inproper connection.

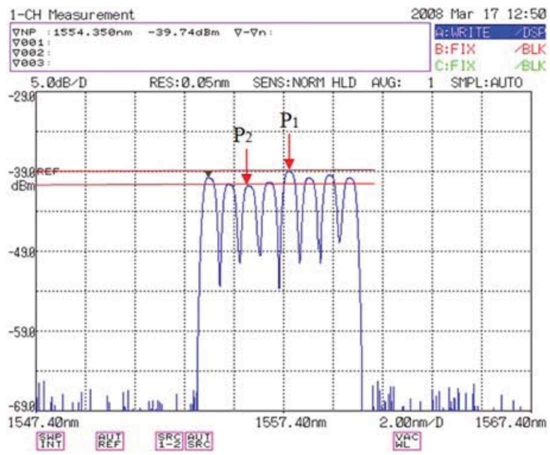

Fig. 8: The uniformity measurement for 8-ports AWG-based OCDMA encoder. Uniformity = Maximum peak power, P1 - Minimum peak power, P2 = (-37.28) - (-38.91) = 1.63 dB.

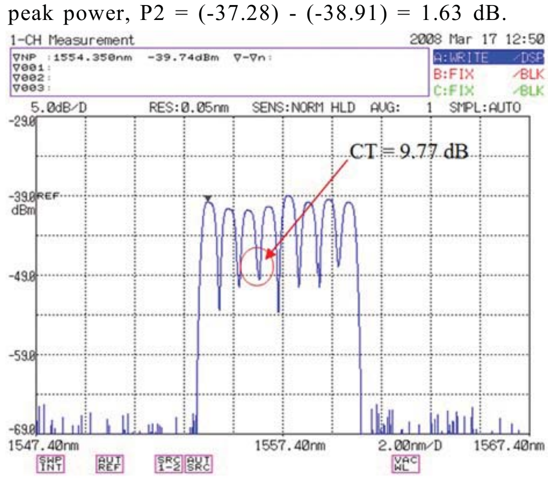

Fig. 9: The crosstalk measurement for 8-ports AWG-based OCDMA encoder. The crosstalk value for the encoder is 9.77 dB.

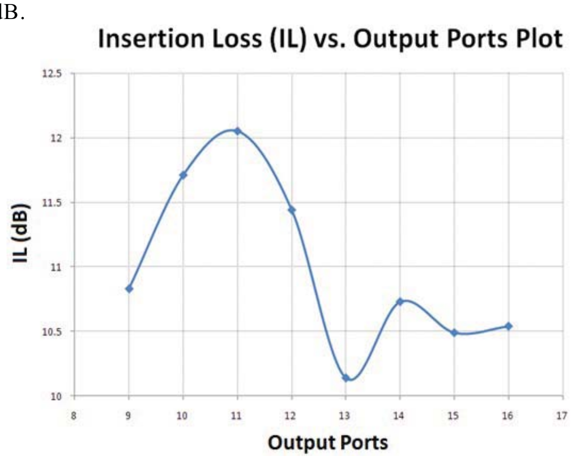

Fig. 10: Insertion loss vs. output ports plot.

Table 3: Insertion Loss

	Broadband Source		TLS Source		
Ports	λc, nm	P, dB	λc, nm	P, dB	IL, dB
9	1544.32	0.00	1554.33	-10.83	10.83
10	1555.13	0.00	1555.14	-11.71	11.71
11	1556.01	0.00	1556.02	-12.05	12.05
12	1556.79	0.00	1556.80	-11.44	11.44
13	1557.57	0.00	1557.59	-10.14	10.14
14	1558.41	0.00	1558.42	-10.73	10.73
15	1559.21	0.00	1559.23	-10.49	10.49
16	1559.99	0.00	1560.01	-10.54	10.54

Table 4: Binary code for signal transmission and OSNR

Binary Code	OSNR (dB)
00000001	-20.00
00000010	-20.00
00000011	-20.00
00000100	-20.00
00001000	-20.00
00001100	-20.00
00010000	-19.07
00100000	-18.72
00110000	-20.00
01000000	-18.75
10000000	-20.00
11000000	-20.00

Signals Selective and Spectral Encoding:

256 binary codes can be produced from 8 optical switches, but acoording to the Enhancement Double-Weight (EDW) theory, only those codes consist 1 or 2 bit '1' can be used for data transmission, the others will repeat the same data in signal delivery. These codes will provide the voltage source to the optical switches either + 5 V or – 5 V. The characterizations for each code can be used in data transmmision are listed in Table 4. Fig. 11 to 22 show code spectrums for data transmission based on EDW theory with wavelength between 1550 nm to 1562 nm.

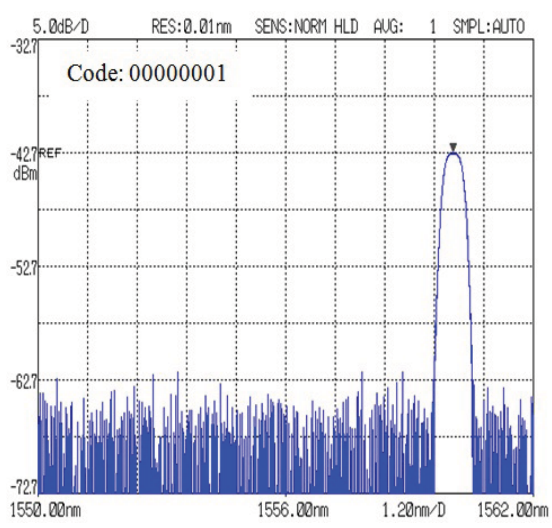

Fig. 11: Spectrum display for code 00000001.

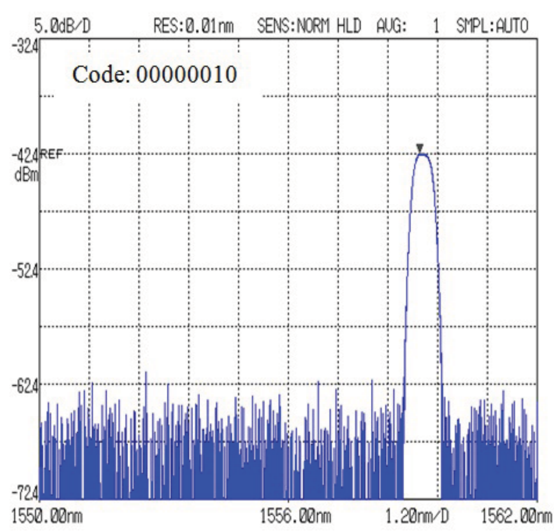

Fig. 12: Spectrum display for code 00000010.

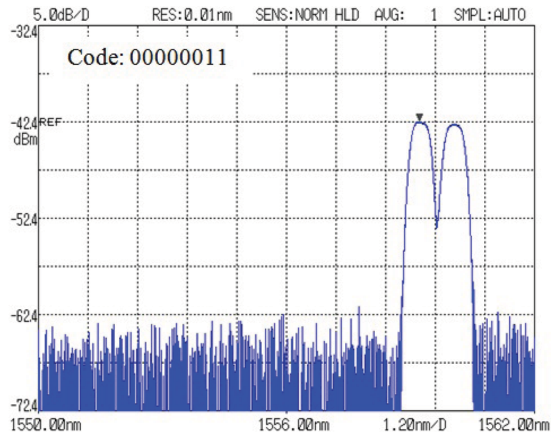

Fig. 13: Spectrum display for code 00000011.

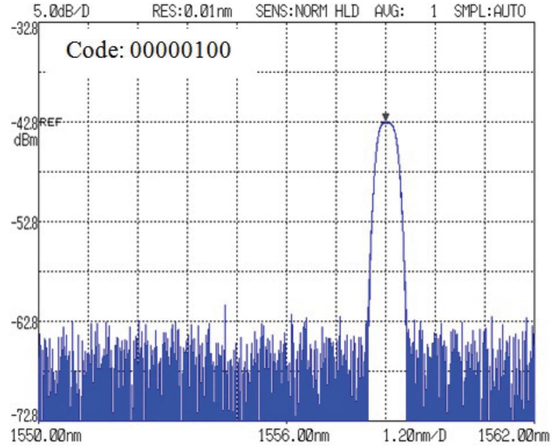

Fig. 14: Spectrum display for code 00000100.

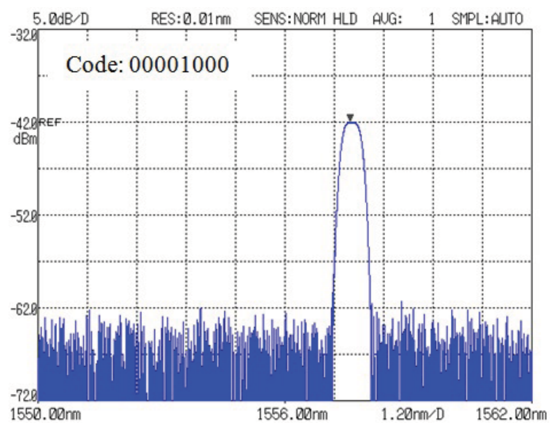

Fig. 15: Spectrum display for code 00001000.

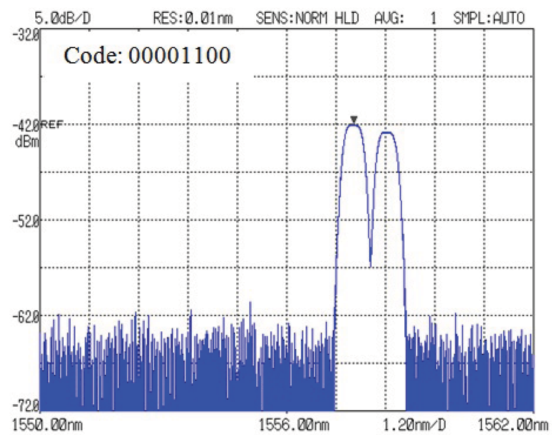

Fig. 16: Spectrum display for code 00001100.

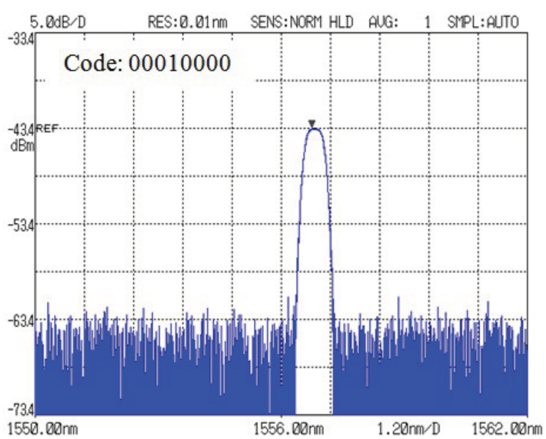

Fig. 17: Spectrum display for code 00010000.

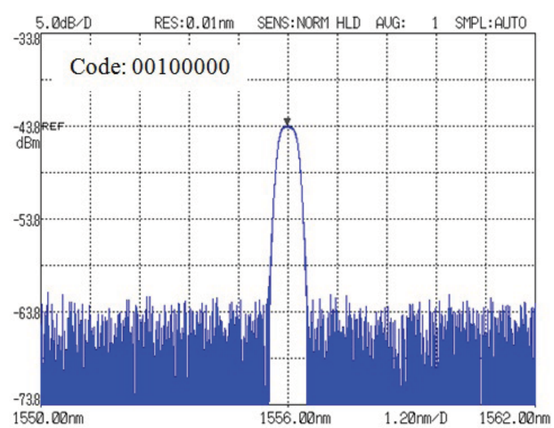

Fig. 18: Spectrum display for code 00100000.

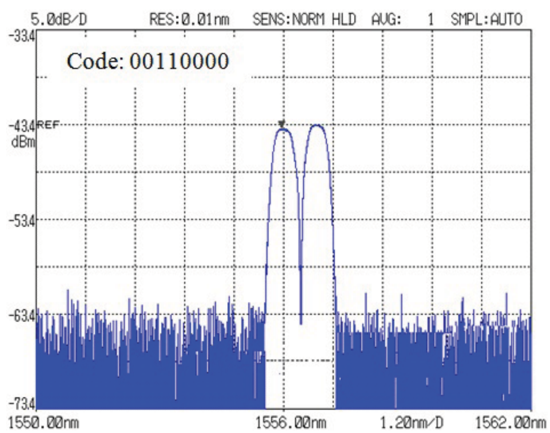

Fig. 19: Spectrum display for code 00110000.

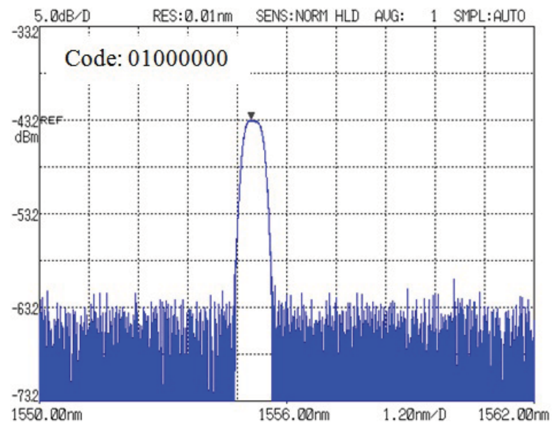

Fig. 20: Spectrum display for code 01000000.

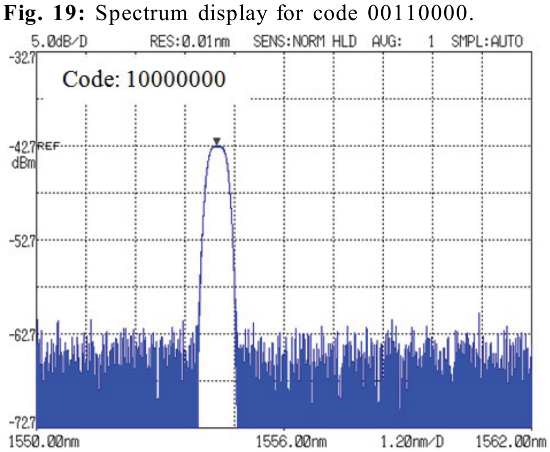

Fig. 21: Spectrum display for code 100000000.

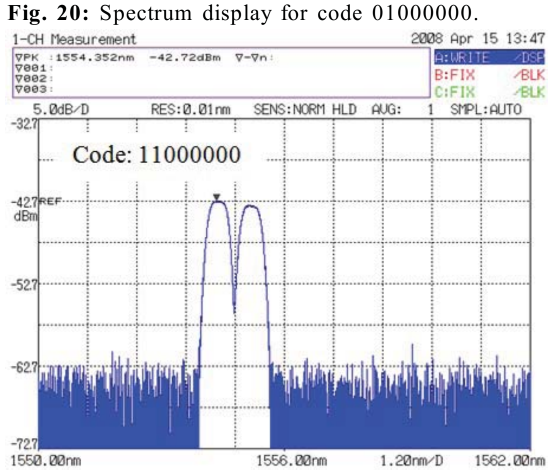

Fig. 22: Spectrum display for code 11000000.

Conclusions and Future Works:

We have proposed an OCDMA encoder optical access network using binary coded AWGs and optical switches. The experimental results showed insertion loss, cross-talk, uniformity, and OSNR are <12 dB, 9.77 dB, <1.63dB, and ≥20 dB. In future research activity, we aim to increase the number of ports to be 32 or 64, greater signals can be coded and delivered. A microprocessor system will develop to replace the DPDT toggle switch for controlling the polarization of voltage source for optical switches.

5. Appendix

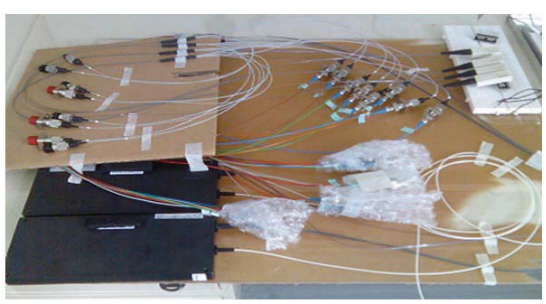

Fig. 23: Photographic view of AWG-based OCDMA encode prototype before chasing.

Fig. 24 and 25: Photographic view of AWG-based OCDMA encode prototype (Front view and back view).

ACKNOWLEDGMENT

The authors are also grateful to the Photonic Technology Laboratory, Institute of Micro Engineering and Nanoelectronic (IMEN), Universiti Kebangsaan Malaysia (UKM), Malaysia for providing the facilities to carry out the experiments. The OCDMA Encoder prototype had firstly been exhibited in 19th International Invention, Innovation and Technology Exhibition (ITEX 2008), Malaysia under telecommunication category.

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