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Low-Cost Encoding Device for Optical Code Division Multiple Access System

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Abstract: Problem statement: Instead of using Fiber Bragg Grating (FBG) to develop the coded spectrums, which consist of expensive elements, the grating also are highly sensitive to environmental changes and this will contribute to the increment of capital and operational expenditures (CAPEX and OPEX). **Approach:** This study presented the development of low-cost 16-ports encoding device for Optical Code Division Multiple Access (OCDMA) systems based on Arrayed Waveguide Grating (AWG) devices and optical switches. The encoding device 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 were 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 encoding device 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 was given, the optical switch will give code '1' and vice versa. **Results:** We found that 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. **Conclusion:** We had successful developed the AWG-based OCDMA encoding device prototype and characterized using linearity testing and continuous signal testing. The developed prototype was expected to be applied in the optical communication system on Passive Optical Networks (PONs).

Key Words: AWG, optical switch, security, data transmission, DPDT toggle switches

INTRODUCTION

The development of fiber optics communication in the last few years has made the optical fiber a strong candidate for the future of telecommunication system. The optical fiber offers a vast amount of bandwidth that can be utilized for communication. One of utilizing this is signal multiplexing. Due to the large bandwidth and the associated high bit rates, the multiplexing process is beyond the capabilities of pure electronic methods and has to be implemented optically as well. Code Division Multiple Access (CDMA) is a strong candidate for creating effective multiple methods for the optical subscriber access network because of its asynchronous access and code multiplexing[1-3].

Code Division Multiple Access (CDMA) is a strong candidate for creating effective multiple methods for the optical subscriber access network because of its asynchronous access and code multiplexing. OCDMA system has attracted increasing attention in recent years due to 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. 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[3].

The main OCDMA methods use the following: 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

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optical wavelength-hopping/time spreading. OCDMA using OOCs has many problems, such as a limitation on the number of distinct code sequences and low optical power because there are fewer 1s than 0s. One of the key issues for OCDMA is to reduce the Multiple Access Interference (MAI) among ports (or users). One study proposed an FBG-based OCDMA with maximal length codes to reduce MAI, where only data 1 is encoded as in the conventional OCDMA on-off shift keying; it has a unipolar capacity. Furthermore, the spectral power distortion effects of the broadband light source were not considered[3].

OCDMA encoding/decoding device: OCDMA is the use of Optical Code Division Multiplexing (OCDM) technology to arbitrate channel access among multiple network nodes in a distributed fashion. OCDM is a multiplexing procedure by which each communication channel is distinguished by a specific optical code rather than a wavelength or time-slot. Encoder/decoder is a pair of devices or subsystems required in an OCDMA system, where the encoder at the transmitter and decoder at the receiver. The function of the encoder is to amplitude-spectrally encode the source according to the specific code it uses. One unique encoded spectrum represents one channel. While a decoder consists of filter arranged in unique configurations with other components. The reverse decoding operation is required to recover the original data[4,5].

There are many different kinds of OCDMA encoders/decoders. Encoder/decoder can be implemented using any types of optical filtering technology, including AWGs, FBGs, free-space diffraction gratings, or thin-film filters[5]. AWG is one of the most promising devices for multiplexer (mux) and demultiplexer (demux) in optical communication system due to the fact that AWG has been proven capable of precisely de(multiplexing) a high number of optical signals with low insertion loss, high stability and low cost[6,7]. AWG was first proposed as a solution to the WDM problem by Smit[8] in 1988 and was further developed in the following years by Takahashi[9] who reported the first devices operating in the long wavelength window. Dragone[10] extended the concept from 1xN demultiplexer to NxN wavelength router, which plays an important role in multi-wavelength network application.

AWGs are optical wavelength (de)multiplexers used in OCDMA. As well as performing basic (de)multiplexing functions, they can be combined with other components to create add/drop multiplexers, used to pipe single wavelengths on and off the network and cross connects, used for routing[11]. These devices can be passive, where the signal routing is fixed according to wavelength, or active, where optical switches are utilized to dynamically route the signals. Both circuits shown are transparent to the data format, can allow bi-directional transfer of information and function entirely in the optical domain.

The key advantage of AWG is its cost do not dependent on wavelength count as in the dielectric filter solution. Therefore it suits metropolitan applications that require the cost-effective of large wavelength counts. Other advantage of the AWG is the flexibility of selecting its channel number and channel spacing. As a result, various kinds of AWG's can be fabricated in a similar manner[12].

For coherent Time-Spreading (TS) OCDMA, multiport AWG OCDMA 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 (CO) of OCDMA network to reduce the number of encoders/decoders. The multi-port 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[13].

MATERIALS AND METHODS

AWG-based encoding device: The 16-ports AWG-based OCDMA encoding device 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. 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. 2.

The encoding device 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. 2 is push up and alters to -5 V when the switch 2 is push down.

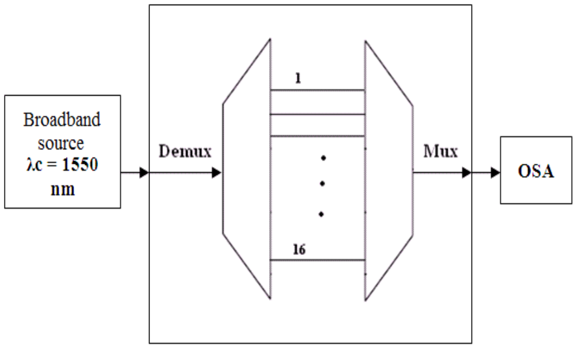

Fig. 1: Block diagram of linearity test for AWG with back-to-back connection

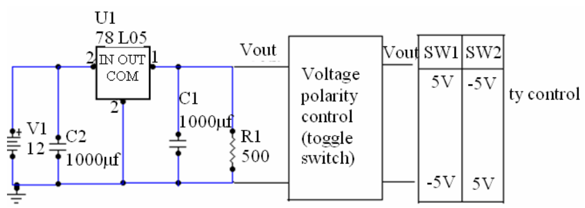

Fig. 2: The voltage regulator circuit and voltage polarity control

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.

RESULT

Characteristics of AWG-based encoding device: Two methods are being used to study the specifications of the 16-ports AWG-based encoding device: Linearity test and continuous signal test.

Linearity test: The linearity adjustment among two AWGs should proceed in designing an encoding device 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.

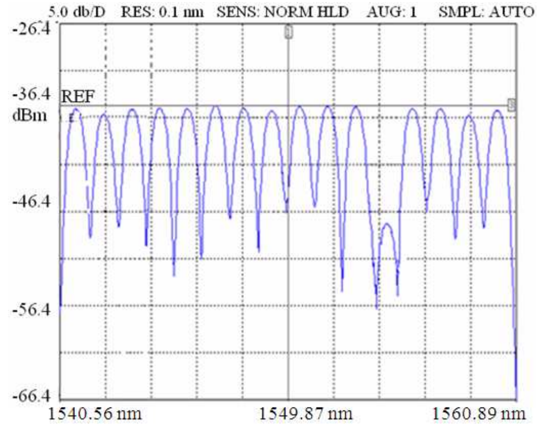

Fig. 3: The spectrum display for AWG back-to-back connection

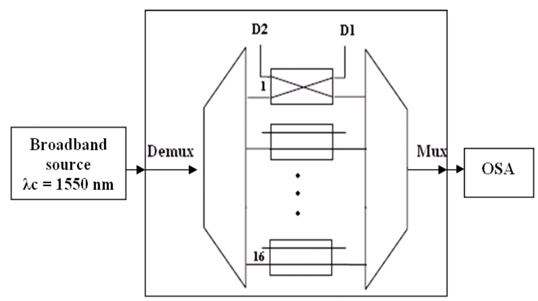

Fig. 4: Block diagram of continuous signal testing for AWGs-based encoding device

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) (Fig. 1). The spectrum display for AWG back-to-back connection is indicated in Fig. 3.

Continuous Signal Test: The parameters of the encoding device such as insertion loss, 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. 4 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.

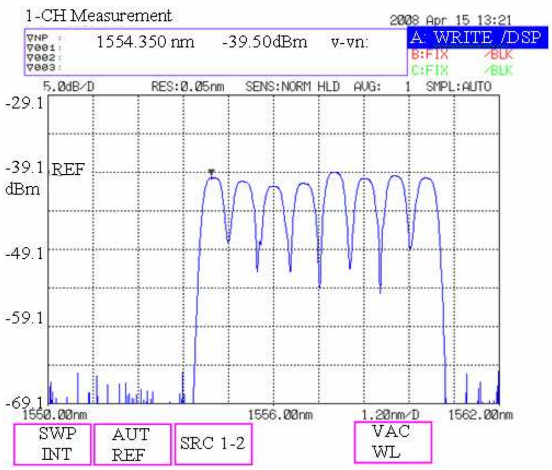

Fig. 5: Spectrum display for 8-ports AWGs-based encoding device

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. Figure 5 Shows the spectrum display for 8-channels OCDMA encoder in OSA when broadband source is given with the binary code 11111111.

Parameters of AWG-Based Encoding Device: Three parameters of the AWG-based encoding device: 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 encoding device is shown in Fig. 6, where:

$$\text{Uniformity} = \text{Maximum peak power, P1} - \text{minimum peak power, P2} \tag{1}$$

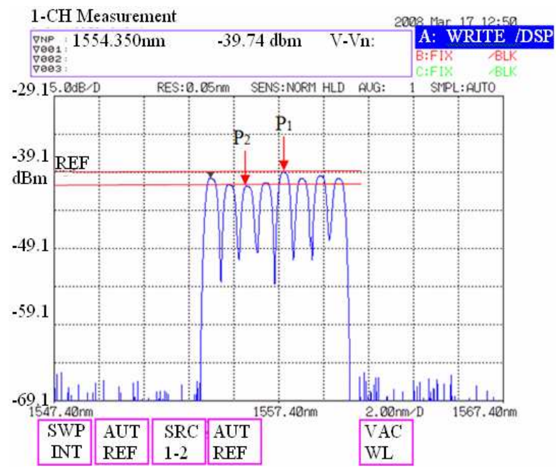

Fig. 6: The uniformity measurement for 8-ports AWG-based OCDMA encoder. Uniformity = (-37.28) -(-38.91) = 1.63 dB

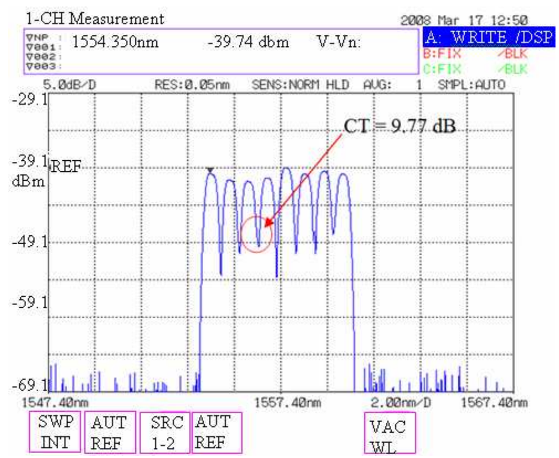

Fig. 7: The crosstalk measurement for 8-ports AWG-based OCDMA encoder. The crosstalk value for the encoder is 9.77 dB

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 (Fig. 7).

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 shown 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 3 m.

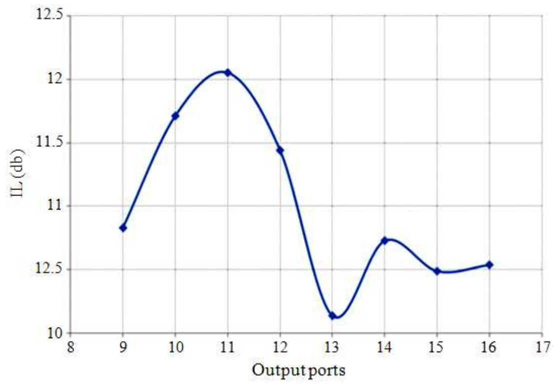

Fig. 8: Insertion loss vs. output ports plot

Table 1: Insertion loss for port 9-16 of AWG-based encoding device

	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

The connector loss is very small and can be neglected. The total losses:

$$\text{Total loss} = [(1.2\times8)+(0.3\times2)+(5.0\times2)]\text{ dB} = 20.2\text{ dB} \quad (2)$$

The calculation for insertion loss is much more higher as compared to the experimental value. The Insertion loss vs. output ports plot is shown in Fig. 8 and Table 1. 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.

DISCUSSION

Signals selective and spectral encoding: About 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 shown in Table 2. Figure 9-12 show code spectrums for data transmission based on EDW theory with wavelength between 1550-1562 nm.

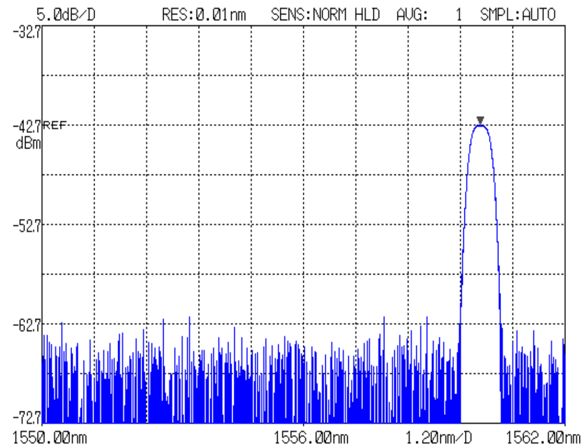

Fig. 9: Spectrum display for code 00000001

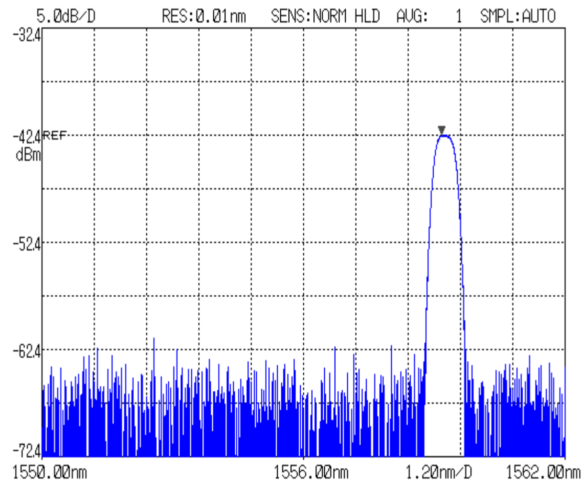

Fig. 10: Spectrum display for code 00000010

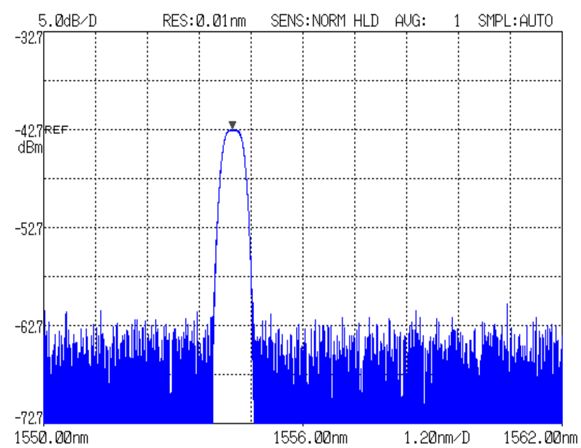

Fig. 11: Spectrum display for code 100000000

Table 2: 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

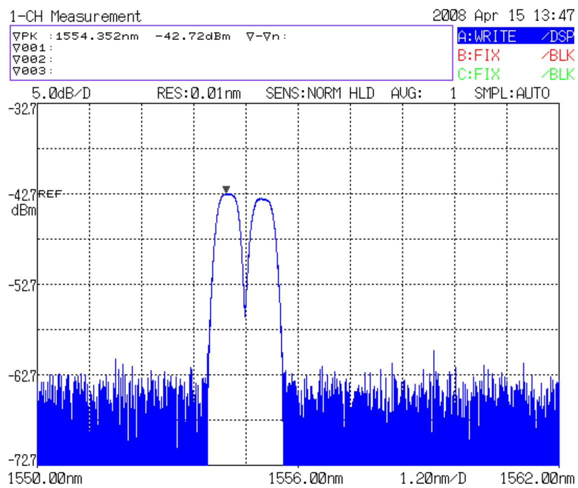

Fig. 12: Spectrum display for code 11000000

CONCLUSION

We have successfully developed an encoding device prototype for OCDMA system using binary coded AWGs and optical switches. The developed prototype had been characterized using linearity testing and continuous signal testing. The experimental results had showed the insertion loss, cross-talk, uniformity and OSNR for the encoding device are <12 dB, 9.77 dB, <1.63 dB and ≥20 dB. The developed prototype is expected to be applied in the optical communication system on PONs. 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.

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