

# The Design and Implementation of Scrambling Wavelength Hopping with AWG Router and Optical Switch over Secure WDM Network

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Received 26 July 2017; received in revised form 13 August 2017; accepted 17 August 2017

## Abstract

In current experimental design, by exchanging the optical switch configured in front of arrayed waveguide grating (AWG) router, the wavelength hopping configuration was implemented over wavelength division multiplexing (WDM) network. In addition, in order to enhance the variable wavelength hopping pattern of proposed scheme, the transceiver oscillators were used to trigger the optical switch by a series of random and unpredictable electrical signal. The experiment results proved possible solution of secure WDM network that the wavelength hopping effect was monitored by optical spectrum analyzer (OSA) in optical domain. By using the oscilloscope for monitoring, the results showed the transmitted analogy signal of 10MHz was extracted correctly by photo-detector while the wavelength hopping is happened.

**Keywords:** arrayed waveguide grating, wavelength hopping, wavelength division multiplexing, optical switch, photo-detector

## 1. Introduction

Improving the confidentiality of access networks has emerged as a critical problem in recent years. It has been shown that optical code-division multiple-access (OCDMA) schemes significantly improve the robustness of optical networks toward malicious attack [1-8]. Generally speaking in confidential topic, the WDM network was viewed as without capability against eavesdroppers' attacking. In order to achieve the confidential ability in wavelength division multiplexing (WDM) network, the arrayed waveguide grating-based (AWG-based) wavelength hopping was presented by one of current authors [9-10]. Unfortunately, the proposed scheme had never been implemented in experiment stage. Here, the possible and feasible configuration was demonstrated in wired WDM network to achieve similarly security mechanism of frequency hopping in wireless communications such as those executed over WiFi network.

## 2. System Architecture and Principles

In current experimental design, the proposed of wavelength hopping configuration for scrambling modulated signal was shown in Fig. 1. For commercial components in practical experiment, the 8×8 AWG router and 2×2 optical switch were exploited. Actually, the only one input port of optical switch was applied and then below-mentioned optical switch could be called 1×2 optical switch.

The SLD light source was applied to provide the three wavelengths of  $\lambda_1=1556.3\text{nm}$ ,  $\lambda_2=1557.1\text{nm}$ , and  $\lambda_8=1562.1\text{nm}$ , respectively. Connecting after the SLD light source, the 1×2 optical switch which triggered by transmitted oscillator was

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used to exchange the optical path to enter arbitrary input port of AWG router (e.g., port #1 – #8 as seen in Fig. 1) while cross (on) and bar (off) state was happened. By employing inherent cyclic and FSR property of AWG router, the AWG router enables realizing  $N \times N$  routers, in which  $N$  input wavelengths (#1 – # $N$ ) were de-multiplexed to  $N$  output ports.

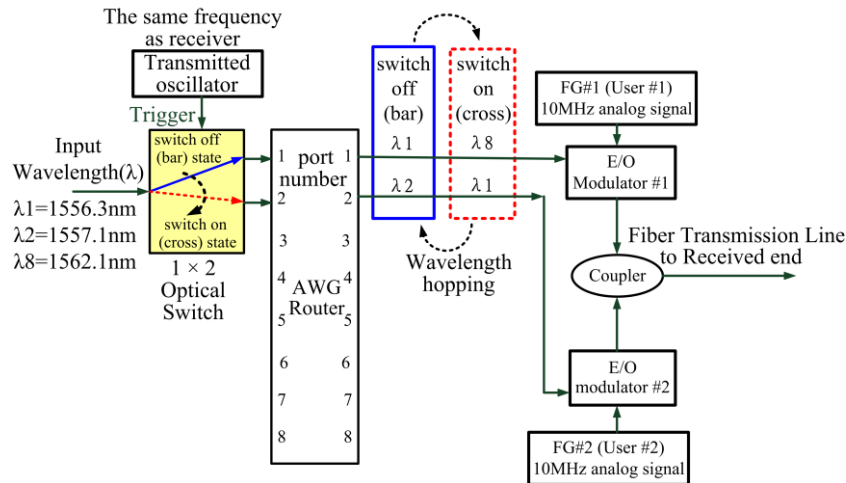


Fig. 1 The proposed wavelength hopping configuration using AWG router and optical switch on the transmitter

Here, the different wavelengths appear in the output port of AWG router as user's carrier and transfer to electro-optics modulator (EOM). The individual wavelength carrier was modulated by the analog signal of 10MHz for each user and coupled into fiber to received end. Finally, the wavelength hopping phenomenon of modulated signal was monitored by optical spectrum analyzer (OSA) and achieved the varying analog signal of 10MHz coming from the different FG#1(User #1) and FG#2(User#2).

Following the cyclic property of AWG, the path of laser source was changed by optical switch from bar (off) to cross (on) state and entered into the different input port of AWG. Hence, the various wavelengths were appeared in original output port of AWG to create the wavelength changing. For changing the wavelength carrier of each user, each user corresponded to perform wavelength hopping and then protected against the un-authorized attacking. In addition, in order to enhance the variable wavelength hopping pattern of proposed scheme, the optical switch could be triggered by transceiver oscillators creating from a series of random and aperiodic electrical signal.

In current practical experiment, the wavelength hopping of FG#1(User#1) was created from  $\lambda_1=1556.3\text{nm}$  to  $\lambda_8=1562.1\text{nm}$  while the optical switch state was converted by transmitter oscillator from bar to cross state. Simultaneously, the wavelength hopping of FG #2(User #2) was created from  $\lambda_2=1557.1\text{nm}$  to  $\lambda_1=1556.3\text{nm}$  while the optical switch state was converted by transmitter oscillator from bar to cross state.

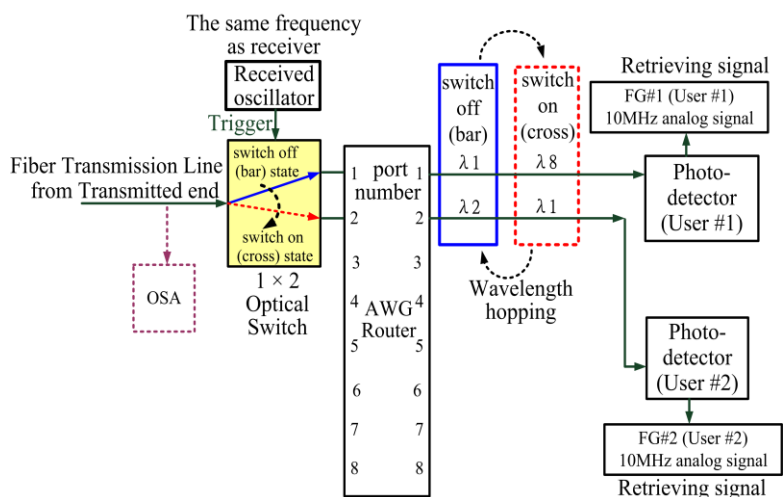


Fig. 2 The proposed wavelength hopping configuration using AWG router and optical switch and on the receiver

On the receiver shown in Fig. 2, the 1×2 optical switch was triggered by received oscillator which had the same frequency as transmitter and decided the state of switch off (bar) or switch on (cross), depending on transmitted end. Finally, the different optical signals appearing in the output port of AWG router were detected through photo-detector to retrieve the different analog signal from FG#1(User #1) and FG#2(User#2). The oscilloscope (OSC) connected the photo-detector to observe the optical signal modulated by analog signal of 10MHz.

### 3. Experimental Result

In current experiment, all the type and specification of using components is summarized in Table 1. In order to guarantee the implementation of wavelength hopping correctly, the monitoring architecture configured with optical spectrum analyzer (OSA) and oscilloscope (OSC) was shown as Fig. 3 on the transmitter. Here, the OSA was used to measure the wavelength hopping happening when the optical switch was triggered by specific sequence (i.e., hopping pattern). Simultaneously, the OSC was used to measure the analog signal of 10MHz when the amplitude of desired signal was retrieved by photo-detector from the specific wavelength.

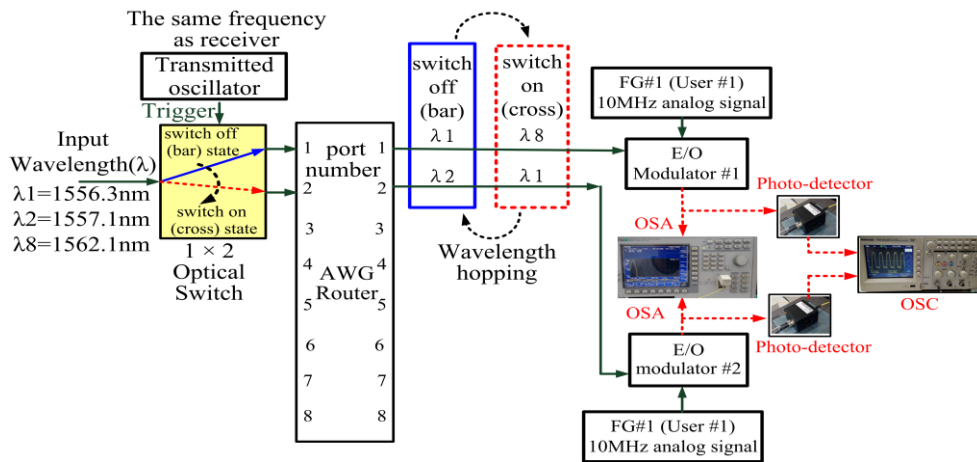


Fig. 3 The monitoring architecture configured with optical spectrum analyzer (OSA) and oscilloscope (OSC) on the transmitter

There were two states of optical switch to be implemented in Fig. 1. The bar (off) and cross (on) of 1×2 optical switch were designed to verify the wavelengths hopping phenomenon, respectively.

Table 1 All the type and specification of using components in current experiment

	Production	Specification
Transmitter	Laser source	NXTAR SLD-2200
	Optical switch	New Port SPSN-9-22-FCAPC
	AWG	DWDM-G-100G-8-8-FC-APC
	Analog signal(10MHz/1MHz)	Twintex TFG-3510
	EOM	Lucent ZX86-12G-S+
	Coupler	CP-S-A-2x2-1550-50/50-900-1-1-3x54mm-FC/UPC
	Fiber	FC/UPC-FC/APC-SM-SX-0.9mm-3M
Receiver	Optical switch	Thorlabs GmbH OSW22-1310E
	AWG	DWDM-G-100G-8-8-FC-APC
	Photo-detector	New Focus model 1611
Measuring equipment	optical spectrum analyzer (OSA)	ANRITSU MS9710C
	Oscilloscope (OSC)	Tektronix TDS2012B

Fig. 4(a) and Fig. 5(a) presented the wavelength spectra on the switch bar (off) state to focus only on the output port #1 and #2 of AWG router. The  $\lambda_1=1556.3\text{nm}$ ,  $\lambda_2=1557.1\text{nm}$  and  $\lambda_8=1562.1\text{nm}$  entered into the input port #1 of AWG router and appeared a pair of (output port #1, output port #2) wavelengths corresponding to ( $\lambda_1=1556.3\text{nm}$ ,  $\lambda_2=1557.1\text{nm}$ ). Actually, the wavelength of  $\lambda_8=1562.1\text{nm}$  appear in the input port #8 of AWG router.

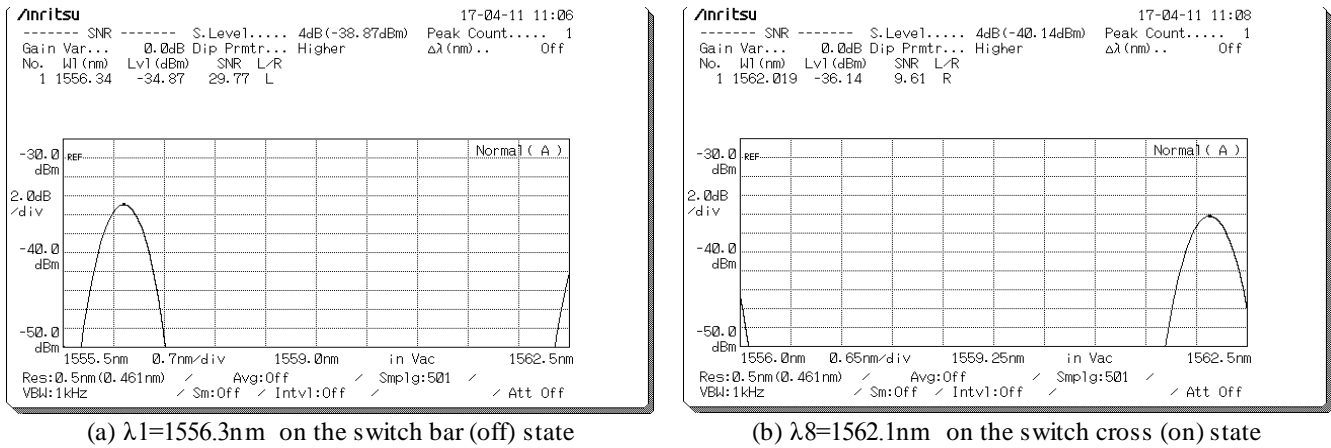


Fig. 4 Appearing wavelength in output port #1 of AWG router

Similarly, as seen from Fig. 4(b) and Fig. 5(b), converting to the switch cross (on) state, the same wavelength of SLD changed the entrance into the input port #2 of AWG router and appear a pair of (output port #1, output port #2) wavelengths corresponding to ( $\lambda_8=1562.1\text{nm}$ ,  $\lambda_1=1556.3\text{nm}$ ). Actually, the wavelength of  $\lambda_2=1557.1\text{nm}$  appear in the input port #2 of AWG router.

By monitoring the switch changing from bar (off) to cross (on) state, the wavelength hopping of FG#1(User#1) was implemented from  $\lambda_1=1556.3\text{nm}$  to  $\lambda_8=1562.1\text{nm}$ . Similarly, the wavelength hopping of FG#2(User#2) was implemented from  $\lambda_2=1557.1\text{nm}$  to  $\lambda_1=1556.3\text{nm}$ .

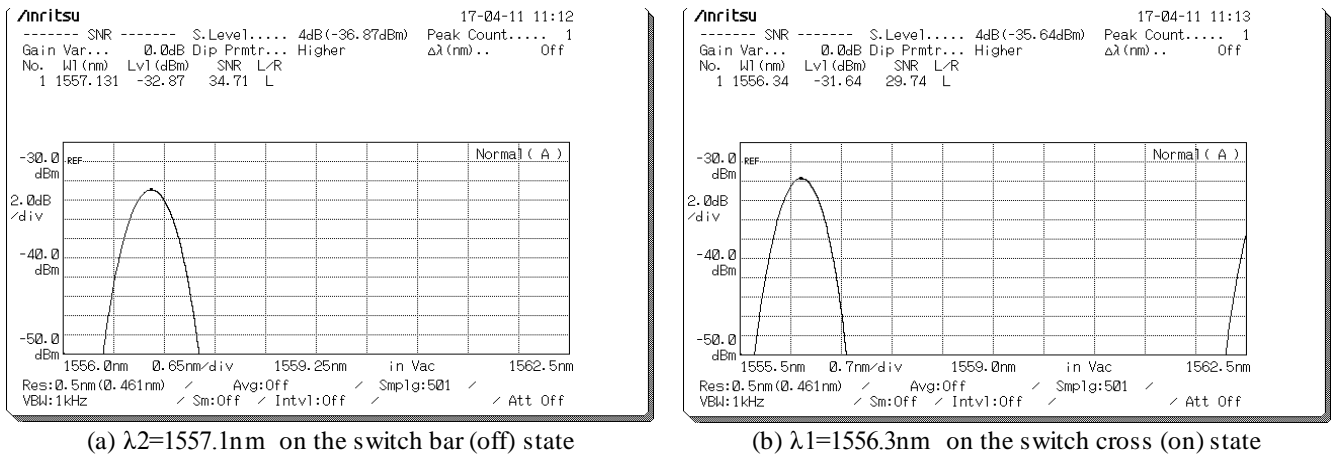
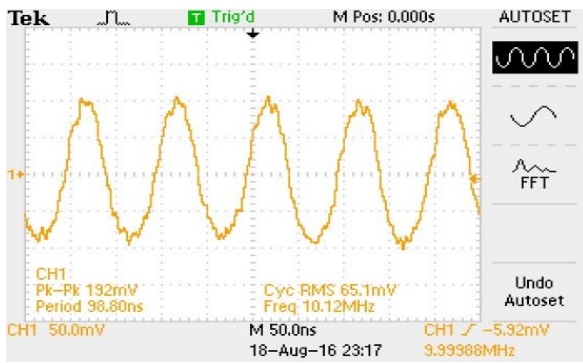


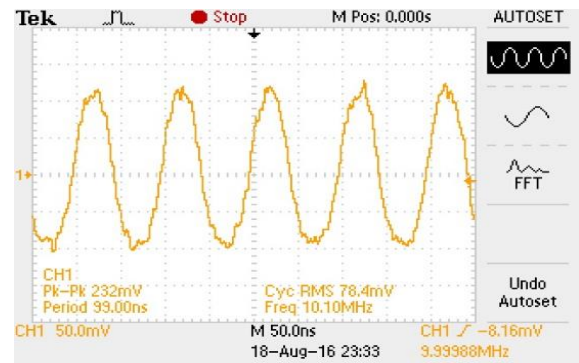
Fig. 5 Appearing wavelength in output port #2 of AWG router

By measuring the appearing output port #1 of AWG router modulated by EOM #1, Figure 6 presented the different wavelengths as carriers which were modulated by the analog signal of 10MHz on the switch bar (off) state or cross (on) state. The oscilloscope (OSC) showed that the individual optical signal could be modulated by the analog signal through electro-optics modulator (EOM) to make the wavelength hopping possible.

Similarly, by measuring the appearing output port #2 of AWG router modulated by EOM #2, the Figure 7 presented the different wavelengths as carriers which were modulated by the analog signal of 10MHz.

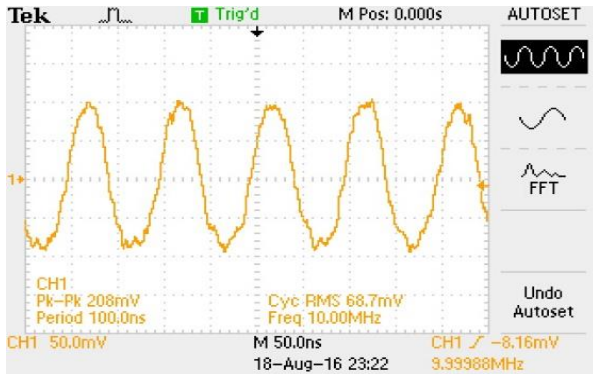


(a)  $\lambda_1=1556.3\text{nm}$  on the switch bar (off) state

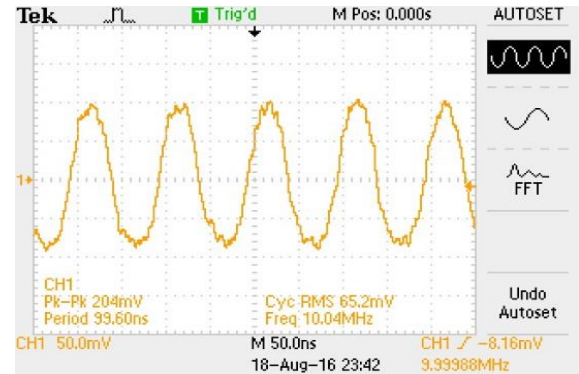


(b)  $\lambda_8=1562.1\text{nm}$  on the switch cross (on) state

Fig. 6 The modulated analog signal of 10MHz appearing in output port #1 of AWG router



(a)  $\lambda_2=1557.1\text{nm}$  on the switch bar (off) state



(b)  $\lambda_1=1556.3\text{nm}$  on the switch cross (on) state

Fig. 7 The modulated analog signal of 10MHz appearing in output port #2 of AWG router

#### 4. Conclusion

In current study, the possible configuration in the wavelength hopping was experimented to achieve the secure modulated analog signal of 10MHz by electrical/optical modulator. The experiment results proved possible solution of secure WDM network that the wavelength hopping effect was monitored by optical spectrum analyzer (OSA) in optical domain. In addition, by using the oscilloscope (OSC) for monitoring the original signal, the results showed the transmitted analog signal of 10MHz was extracted successfully by photo-detector while the wavelength hopping was happened. In near future works, by replacing 10MHz analog signal with video stream, the desired converting interface of video and binary data bit (i.e., either bit 0 or 1) will be installed. The experiment will be investigated to extract and recovery the video signal correctly. Furthermore, a secure wavelength hopping scheme will be implemented and verified to apply in multimedia application.

#### Acknowledgment

This study was supported under grant Nos. MOST 105-2221-E-244-004 and MOST 104-2221-E-150-043.

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