MRR Filter Characterizations in WDM System for Digital Signals Transmissions

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***Abstract*— This paper discusses the implementation, capabilities and limitations of Microring Resonator (MRR) filter in the Wavelength Division Multiplexing (WDM) system, particularly as a wavelength selector components for high-speed (> 2.5 Gbps) WDM digital systems. To accommodate the demand for telecommunications traffic growth, WDM technique is widely used in optical communication networks to grant for more information to be shared through the same physical transmission channel. In general, the performance of the system in terms of bit error rate (BER) and system quality factor (Q) is described. The performance of WDM system with MRR filter as the wavelength selector has been studied for the first time in this paper.**

***Index Terms*— Microring resonator, Optical filter, Wavelength Division Multiplexing System.**

I. Introduction

WDM system is the most suitable technology for utilizing fiber optic bandwidth, where the transmitter and receiver provide access to convert electrical signals into optical signals and vice versa. The optical filter has the ability to select and separate specific wavelengths, increase the efficiency of the optical system and indirectly resolve the transmission line conflicts when it carries a variety of different wavelengths at the same time. However, due to the very high operational cost, it is effective to examine how the wavelength selection affects the performance of an overall optical WDM network [1-2].

The main focus of the modern optical system is to generate, manipulate, drive, and detect light signals, and eventually perform the processing applications. In addition to the basic components in the optical circuit blocks such as optical light source, detector and optical fiber, other components that are no less important are the amplifiers, modulators, optical switches and filters, which are currently based on silicon-on-insulator (SOI) platform [3-6]. To date, several filter structures have been proposed such as Arrayed Waveguide Grating (AWG), Fabry-Perot (FP) and Mach-Zehnder (MZ) interferometers [7-8]. However, the performance of these structures is poor in terms of passband flatness and crosstalk. Moreover, robust electronics are necessary in order to stabilize the central wavelength. Therefore, an option for these structures is crucial especially for dense wavelength division multiplexing (DWDM) optical networks applications.

Optical filter proposed in this study is a potential for wavelength selection or demultiplexer in optical integrated circuit chip. This is due to its very small size and ease of integration with other optical devices. The Microring Resonator (MRR) optical filters are proposed in this study for WDM networks with the speeds of 10 Gbps and 200 GHz channel spacing, as shown in Figure 1. The applications of MRR is to choose a unique wavelength from multi-channel signals carried by the WDM system and send only one channel to a specific port [9-10].

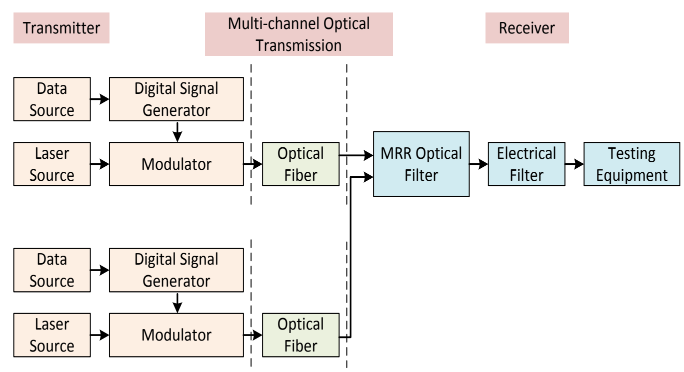

Figure 1: An example of 2 channels optical communication systems for digital data transmission

A transmitter for digital data transmission comprises data source generator, digital signal generators, laser sources and modulator. Pseudo random bit sequence (PRBS) generator is used as a data source that provides the basis for the binary pattern formation. The bit sequence is fed into the generator using digital signal modulation techniques such as non-return-to-zero (NRZ), return-to-zero (RZ) and bipolar signal for generating electrical code [11]. The focus of the study is to use polar modulation coding with NRZ format. This is due to the suitability of the proposed network application for data transmission in WDM networks and existing facilities in Malaysia. Laser sources used in the study is a continuous wave laser (CW), while the Mach-Zehnder modulator is used as a modulator to perform the conversion of electrical signals into optical signals.

Optical fiber used as the optical transmission line has many excellent characteristics as a physical medium for high-speed networks such as low attenuation, large bandwidth and low transmission error rates. In this study, optical fiber operation is affected by 16 ps/nm dispersion and an attenuation of 0.2 dB/km at each reference frequency [12].

PIN photodiode is applied to detect optical signals and to convert them to electrical signals, while Bessel types electrical low pass filter is used to filter the electrical signals, wherein these signals are then fed to the 3R regenerator (re-amplifying, reshaping, retiming). The results were observed using testing tools such as bit error rate (BER) analyzer to determine the performance of the WDM system.

The quality factor (Q) shown by the BER analyzer is represented by digital signals eye aperture size and can be calculated by the following equation:

$$Q = \frac{|\mu_1 - \mu_0|}{\sigma_1 - \sigma_0} \quad (1)$$

where μ_1 is the average value of the logic level '1' and μ_0 is the average value of logic level '0'. σ_1 is the standard deviation of the optical noise level for logic '1' and σ_0 is the standard deviation of the optical noise for logic level '0'. The reliability of a network observed by BER value occurs when the photodetector could not distinguish between the signal or noise and cause errors. BER can be calculated by the following equation:

$$BER = \frac{1}{2} erfc\left(\frac{Q}{2}\right) \quad (2)$$

where *erfc* is the complementary error function.

The analysis of the MRR filter functionality as optical filter or demultiplexer for WDM network in this study is significant because it represents the areas of potential and there has been an evolving interest in the development of MRR-based devices motivated by the potential to provide a reliable low-cost alternative to other photonic configuration [13-14]. Furthermore, the study of the MRR device applications in optical networks is currently still in its early stage and there are still many technical challenges need to be comprehended.

II. Methodology

To test the functionality of the proposed filter in WDM network, a subsystem model as in Figure 1 was built using Optisystem software. MRR optical filter proposed in this study has a radius of 6.5 µm, a gap size, g of 200 nm and a core size of 120 nm x 400 nm as shown in Figure 2. Other important parameters used in the simulations are shown in Table 1.Eight channels at different wavelengths were used as a signal transmission medium with a channel separation of 200 GHz and the input power of 0 dBm. Optical spectrum analyzer (OSA) serves to display the spectrum of the modulated optical signals in the frequency domain, while the total power in each channel was measured by WDM analyzer. At the receiver, MRR filter will separate the optical signals into different wavelengths.

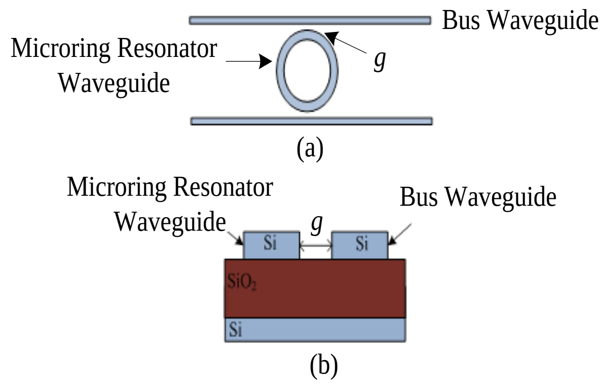

Figure 2: Schematic diagram of the MRR Configuration (a) top view (b) cross-section view

Table 1
Simulation Parameters

Parameter	Value
Si refractive index	3.475
SiO_2 refractive index	1.475
Air refractive index	1
Temperature (K)	300

To conduct an in-depth study of the MRR optical filter performance as a wavelength demultiplexer, the network settings were focused on eight channels WDM system in order. Each channel was modulated with a data rate of 10 Gbps using NRZ format and distribution of optical frequencies of 200 GHz based on ITU-T G.692 frequency grid recommendation for optical fiber applications based on ITU-T G.652 [15]. The effect of nonlinear Self Phase Modulation (SPM) was activated and the noise on the receiver was set as random and not correlated.

III. Results and Discussion

This part discusses the capabilities and limitations of optical MRR filter in the system Wavelength Multiplexer (WDM).

A. Effect of the number of channel to WDM Network Performance

To see the effect of number of channels to WDM transmission network, three different channels was fed to the WDM multiplexer. BER and Q results for multi-channel transmission are shown as in Figure 3 and Figure 4. The dependency of BER and Q to the number of channel can be observed: Higher number of channel contributes to lower Q and greater BER.

Also highlighted is that the Q value reduces almost double when the number of channels is increased from 2 channels to 8 channels. Higher number of channels is vulnerable to crosstalk caused by signal leakage between channels, thus further contributes to the system performance degradation. The standard minimum value of BER is $1x10^{-9}$ or Q must be more than 6 for most optical communication systems, required as the needs of the operation [16]. Both graphs prove that MRR filter plays an excellent role as an optical demultiplexer, in which the BER obtained for eight channels network is approximately $1x10^{-21}$ at 0 km.

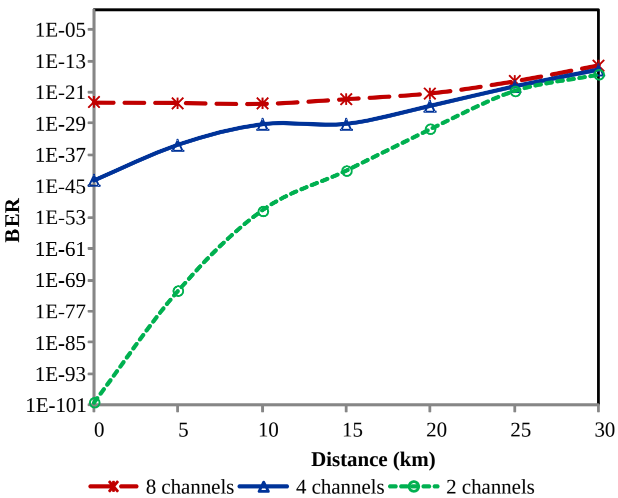

Figure 3: BER against distance for various number of channels

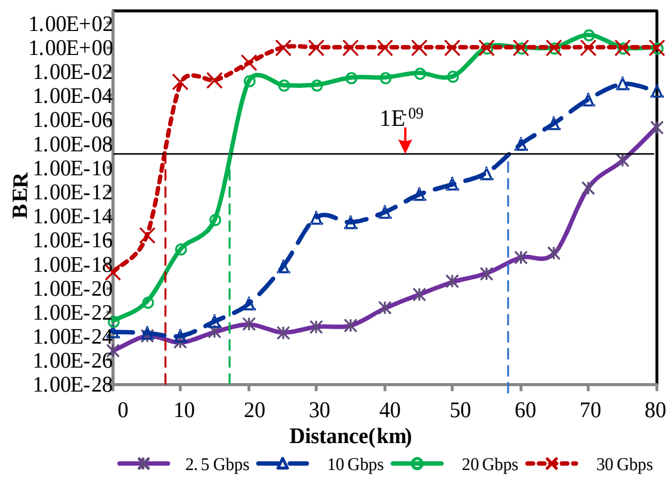

Figure 5: BER against distance for different data rates

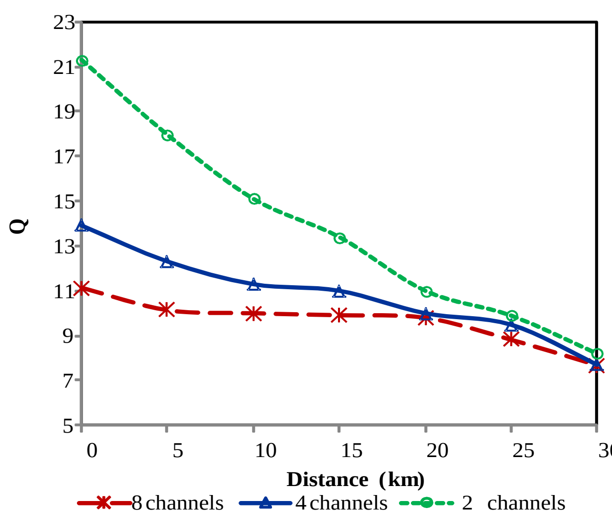

Figure 4: Q against distance for various number of channels

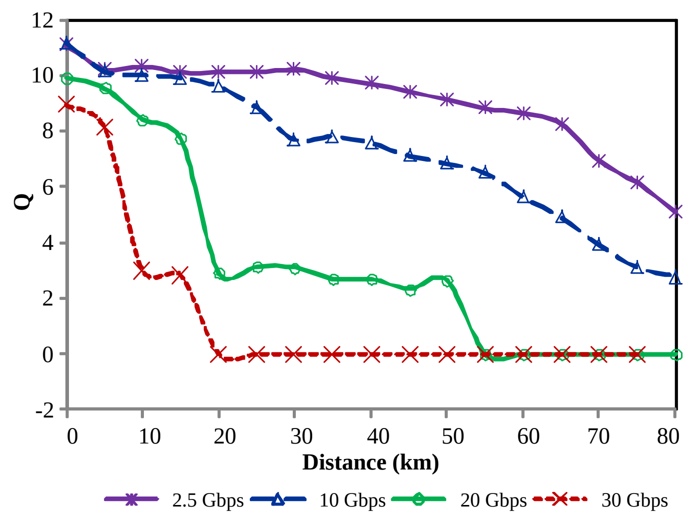

Figure 6: Q against distance for different data rates

B. Effects of the Data Rate on WDM Networks Performance

Using the same parameter setting, the effect of data rate variations to the digital transmission was executed and the results are shown in Figure 5 and Figure 6. For both figures, taking into account the acceptable value of BER <$1x10^{-9}$ and Q> 6 for standard data transmission, eight channels of WDM network system using the proposed filter is effective for less than 8 km for a data rate of 30 Gbps, 18 km for 20 Gbps and 58 km for 10 Gbps. For a signal transmission with a data rate of 2.5 Gbps, the maximum distance reached over 75 km with an input power of 0 dBm. Taking advantage of the amplifier is expected to improve the network performance and the communication distance can be increased.

IV. Conclusion

A detailed study of the performance of an optical communication system has been carried out to predict the functionality of MRR filter in WDM networks and transmission limitations factors, such as distance, number of channels and data speed has been investigated. As compared to other types of optical filter such as arrayed waveguide grating (AWG), Fiber Bragg Grating (FBG) and grating plane, this study was the first attempt to prove that the MRR has excellent performance in WDM network. Most of current studies are still at the device level. In this paper, the potential of MRR as one of the key elements in optical devices development has been reviewed. This study is important guideline to enhance the performance of optical filters, which in turn will improve the overall performance of WDM high speed networks.

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