

Effects on Electrical Filter for 2.5 Gbps WDM-PON based on RSOA Using 100 GHz Spectrum-Sliced Incoherent Light Source

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Abstract— A WDM-PON based on RSOA using spectrum-sliced incoherent light source has been widely researched through commercial service of 100 GHz spacing, 1.25 Gbps transmission, and continues to be researched on 100 GHz, 2.5 Gbps transmission for upgrading network capacity. However increasing the network capacity causes significant noise generation. In order to reduce the noise, we experimented and simulated electrical filtering for increasing the receiver performance on this architecture. Through our work, we found the optimum filter band-width for suppressing received noise, and the possible band-width range on the receiver.

Keywords— Optimum Electrical band-width, BLS, RSOA, WDM-PON

I. INTRODUCTION

A Wavelength division multiplexed – passive optical network (WDM-PON) based on a reflective semiconductor optical amplifier (RSOA) using a spectrum-sliced incoherent light source has been widely researched due to simple architecture, easy operation and management, low-cost implementation and so on. Although the fact that the commercial service was started with a WDM/TDM hybrid-PON based on the same architecture shows us that this method is easy to upgrade the transmission capacity through one feeder fiber, this architecture has more demand on the capacity to accommodate legacy PON like 2.5 Gbps G-PON, and to increase the number of subscribers [1]. For this reason, 200 GHz spectral width should be reduced to 100 GHz, and 1.25 Gbps per subscribers should be upgrade to 2.5 Gbps.

However, if reducing the spectral width from 200 GHz to 100 GHz or speeding up the transmission speed from 1.25 Gbps to 2.5 Gbps, several problems are appeared to transmit signal. The property of the frequency response of a commercialized RSOA has lack of 2.5 Gbps transmission, and the excess intensity noise (EIN) from the broadband light source (BLS) and the spectrum-slicing noise from WDM filtering are increased. Moreover polarization mode dispersion (PMD) and chromatic dispersion (CD) of fiber

affect broadening signal and increasing EIN [2]. First of all, we focused on reducing the signal-to-noise and noise-to-noise beating noise through electrical filter. Thus this paper shows the performance improvement with respect to the electrical bandwidth (BW) of the receiver. We found the optimum electrical BW and the possible BW range for the receiver performance through this work.

II. ELECTRICAL BW

The transmitted optical signal is changed by optical components and includes noise through a link. This can be presented as Eq. 1.

$$E = HS + W \quad (1)$$

where ‘E’ is the received optical signal before a photo-detector (PD), ‘H’ is the frequency response of a total optical channel, and ‘W’ is added noise. A PD converts the received signal (‘E’) by square-law detection, and Eq. 2 is the detected current by a PD.

$$\begin{aligned} \bar{I} &= RP_{IN} \\ &= R|E|^2 \\ &= R(|SH|^2 + (SH)W^* + (SH)^*W + |W|^2) \end{aligned} \quad (2)$$

The first term of the bottom of the Eq. 2 is the transmitted signal and its change. Second and third term is signal-to-noise beating noise. The last term is optical noise. But the PD generates additional electrical noise like shot noise and thermal noise. Thus, the signal after receiver consists of the transmitted signal, the optical noise, the signal-to-noise beating noise, the shot and thermal noise generated by receiver, and so on [3]. The equation of the signal after filtering this received signal is Eq. 3.

$$I = \bar{I}' \frac{B_e}{B_o} + i_{shot} + i_{thermal} \left(\because \bar{I}' = B_o \bar{I} \right) \quad (3)$$

where ‘B_e’ is the electrical BW and ‘B_o’ is the optical BW. ‘i_{thermal}’ is the thermal noise current, and ‘i_{shot}’ is the shot noise current. Two electrically generated noises are Gaussian processes, and the noise powers are Eq. 4.

$$\sigma_{shot}^2 = 2e\bar{I}B_e$$

$$\sigma_{thermal}^2 = \frac{4K_B T}{R_L} B_e$$
(4)

where ‘e’ is the electronic charge, ‘K_B’ is the Plank’s constant, ‘T’ is the temperature, and ‘R_L’ is the receiver load resistance. Equation 2 to 4 shows that the signal current and all noise currents are affected by the electrical BW. As the electrical BW increase, the signal power and all noise powers are increased, and as the electrical BW decrease, the signal power and all noise powers are decreased. However, since the degree of power change with respect to the electrical BW differs from the signal power to the noise power, the optimum electrical BW is different among systems, and how to decide the receiver electrical BW is trade-off. Thus we simulated the Q-factor after various filtering with experimentally measured raw-data.

III. EXPERIMENTS AND SIMULATION

The experimental set-up is Fig. 1.

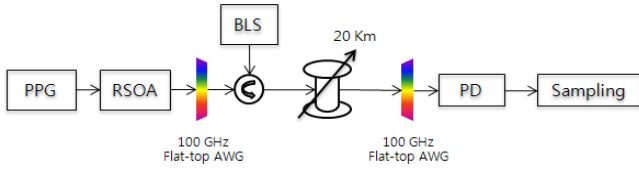


Fig. 1 Experimental Set-up

At the experiments, modulation speed was 2.5 Gbps, 2⁷-1 PRBS pattern was used, and the center wavelength of 2 array waveguide gratings (AWG) is 1535.04 nm. The AWGs are 100 GHz flat-top type, and a BLS was used for seed-light source. The RSOA transmitted signals through 20 km feeder fiber due to general PON architecture has 20 km feeder fiber. And the received optical power before PD was -12 dBm, and we gathered raw-data through a 40 GS/s sampling device. This raw-data was filtered with various filter BWs and estimated signal quality (Q-factor) through a personal computer simulation.

The eye-diagram of the raw-data is Fig. 3. Before filtering, the received signal has poor eye-opening, and the Q-factor is 4.33 (Linear Q). The performance of this signal is too low to transfer signals.

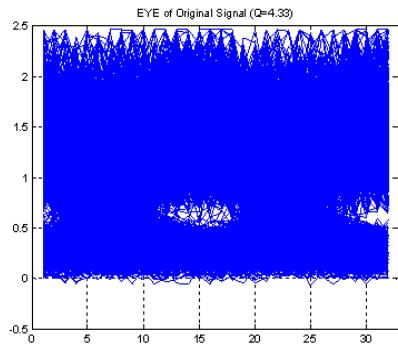


Fig. 2 Eye-diagram of the raw-data

To reduce the noise, we used 2 types of filters in the simulation. The first filter type is ‘maximally-flat filter’. The properties of this filter type are that the pass-band has little amplitude and phase distortion, but that the skirt of the frequency response of the filter is long. The other filter type is ‘Chebyshev 3rd filter’. This filter has sharp stop-band, but the filtered signal has amplitude and phase distortion. These 2 types are representative of filters. The other important factor of filter is filter order. Several hundred order filter simulation is possible, but it cannot be implemented. The useful filter order is 4th or 5th filter because filter order means physical filter size. At the real transceivers such as a small form factor pluggable (SFP) and a gigabit interface converter (GBIC), a trans-impedance amplifier (TIA) performs an electrical filter, and the filter properties are like 4th or 5th filter. Therefore ‘maximally-flat 4th order filter’ and ‘Chebyshev 3rd 4th order filter’ were used in our simulation.

Figure 3 is the frequency response of 1600 MHz maximally-flat 4th order filter, and figure 4 is the frequency response of 2000 MHz Chebyshev 3rd 4th order filter.

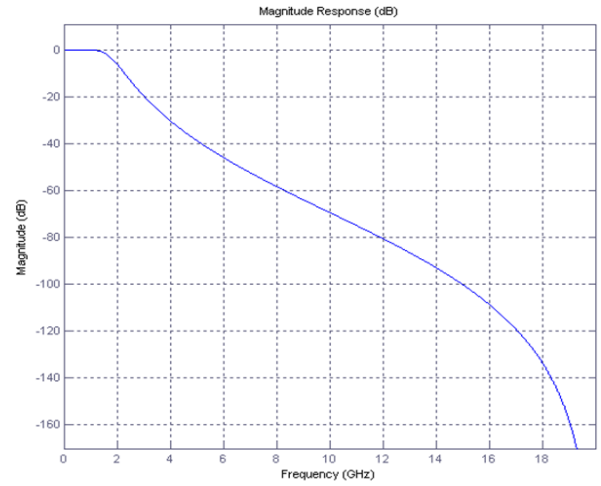


Fig. 3 Frequency response of 1600 MHz Maximally-Flat 4th order filter

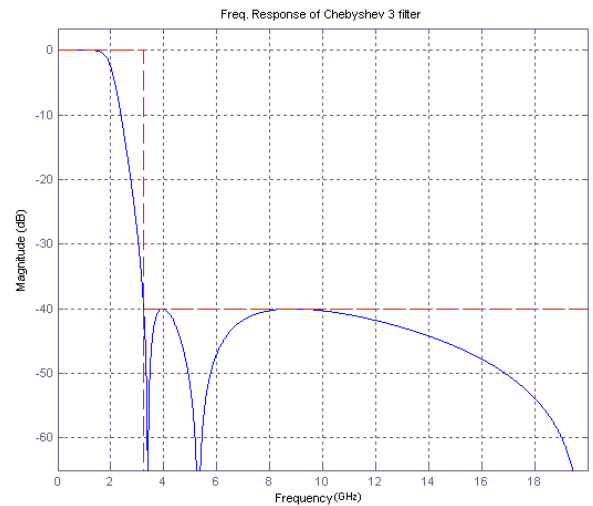


Fig. 4 Frequency response of 2000 MHz Chebyshev 3rd 4th order filter

Because of the practical implementation, the simulation step of the filter 3dB BW was 100 MHz. And the filtered signal qualities were estimated by Q-factor.

IV. SIMULATION RESULTS

The results of this simulation are Fig.5, and Fig.6. Y-axis is Q-factor (Linear), and X-axis is 3dB cut-off frequency of each filter. The optimum maximally-flat filter BW was 1600 MHz, and the optimum Chebyshev 3rd filter BW was 2000 MHz.

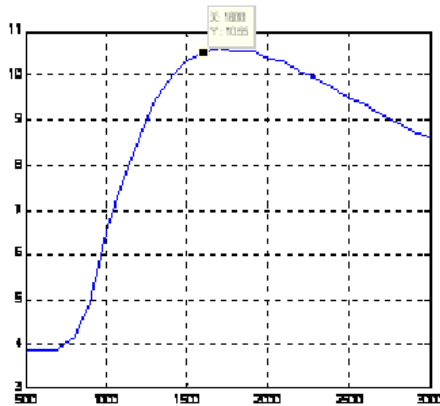


Fig. 5 Q-factor w.r.t. 3dB cut-off freq. with maximally-flat filter

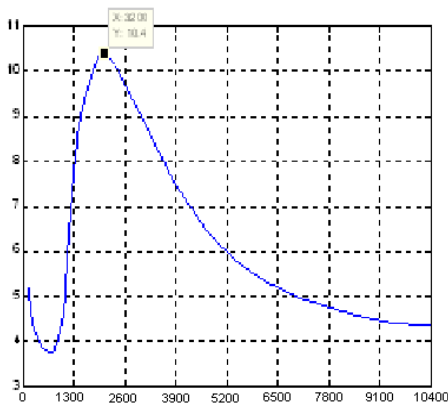


Fig. 6 Q-factor w.r.t. 3dB cut-off freq. with Chebyshev 3rd filter

Generally the required BER for error-free transmission at PON is 10^{-12} . This reveals that over 7 of linear Q-factor submit the minimum performance. Moreover over 10 are required because a TIA, a limiting amplifier, and so on after TIA block generate noise. Through this requirement, the range of maximally-flat filter 3dB BW is from 1400 to 2200 MHz, and the range of Chebyshev 3rd filter 3dB BW is from 1800 to 2200 MHz.

The results of maximally-flat filter are the same as generally known 3dB BW, 70 % of bit-rate, but the results of Chebyshev 3rd filter are quite different, 80 % of the bit-rate. And the optimum performance of maximally-flat filtered signal is little better than that of Chebyshev 3rd filtered signal.

Figure 7 and 8 are the eye diagram of the signal filtered by 1600 MHz maximally-flat 4th order filter and that of the signal filtered by 2000 MHz Chebyshev 3rd 4th order filter. Q is 10.66 in fig. 7, and Q is 10.39 in fig. 8. The amplitude of the signal is modified for making that the average signal power is one. These two eye opening show that the electrical filter dramatically reduces the noise, and easily compared with the eye diagram in fig. 2.

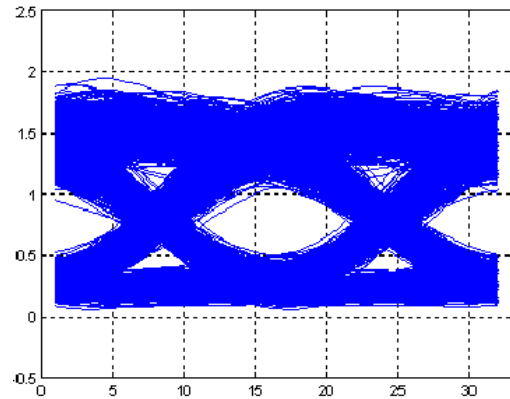


Fig. 7 Eye diagram of the signal filtered by 1600 MHz maximally flat 4th order filter

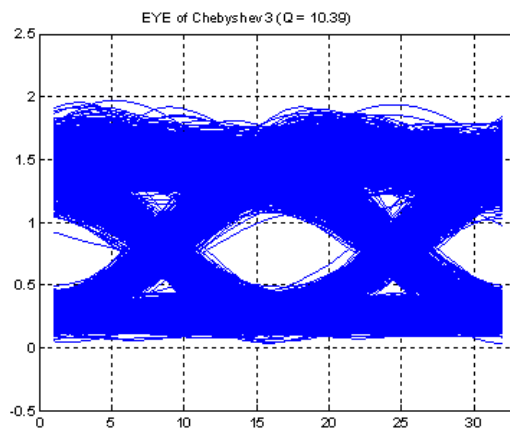


Fig. 8 Eye diagram of the signal filtered by 2000 MHz Chebyshev 3rd 4th order filter

V. CONCLUSIONS

This paper obtained the optimum electrical filter BW through experiments and simulation for 100GHz spacing 2.5 Gbps WDM-PON based on a RSOA using BLS spectrum-sliced incoherent source. The optimum BWs are about 1600 MHz in maximally-flat filter, and about 2000 MHz in Chebyshev 3rd filter. The first value is similar to the general OOK filter BW, which is 70 % of the signal BW, but the other value is not generally known, which is 80 % of the signal BW. Moreover we could know that the maximally-flat filter BW from 1400 MHz to 2000 MHz, and the Chebyshev 3rd filter BW from 1800 to 2200 MHz have little effects for the signal performance. It is because below under limits signal power decrease abruptly, and over upper limits noise power is more

increased than the signal powers. Furthermore Q-factor before filtering is 4.33, which means that the transmission is impossible without filtering. However Q-factor after filtering is over 10, and we could obtain the filter BW for error-free transmission.

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