# 210 Km Long Incoherent WDM Spectrum-Sliced System Running at 10 Gb/S Incorporating Semiconductor Optical Amplifier (SOA) Enhancements

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## ABSTRACT

The deployment of more economical and cost-effective wavelength division multiplexing (WDM) solutions for access and metro networks still remains a key research focus. This paper reports on significant performance enhancement improvements of a highly economical, four channel totally incoherent spectrum-sliced WDM system with the incorporation of a Semiconductor Optical Amplifier (SOA) placed in one of its channels. The baseline system was shown to operate well at 10 Gb/s at a maximum link length of 210 km, demonstrating average Q-factor and signal-to-noise ratios (SNRS) over the four channels. However, the introduction of a single saturated SOA and a single filter placed on one channel yielded a sizable improvement in the Q-factor and exceptional improvement in the measured signal-to-noise ratio (SNR), effectively allowing a further 130 km link travel length whilst still yielding acceptable signal quality – making a total link length of 340 km for one channel.

**Keywords:** spectrum, slicing, amplifier, link

## INTRODUCTION

Wavelength Division Multiplexing (WDM) is the cornerstone of modern optical networks, enabling the vast data capacity required by global internet traffic [1]. While systems employing coherent lasers offer high performance, their cost is prohibitive for many access and metro-network applications [2]. Spectrum-sliced systems using incoherent light sources, such as Amplified Spontaneous Emission (ASE) sources or Light Emitting Diodes (LEDs), remain a compelling, low-cost alternative for specific applications, including Passive Optical Networks (PONs) [3], low-speed Local Area Networks (LANs) [4], and Optical Coherence Tomography (OCT) or biomedical systems [5]. In these architectures, a single broadband source is spectrally sliced into multiple WDM channels using narrowband optical filters, eliminating the need for an array of expensive individual coherent lasers [6].

Table 1 summarizes recent practical achievements in incoherent spectrum-sliced WDM systems. Key takeaways include: the fastest demonstrated in a lab is ~40–50 Gb/s over short distances [7], whereas the longest achieved practical link is ~40 km at 3 Gb/s per channel [8]. For example, an ultranarrow spectrum-sliced incoherent source carried 10 Gb/s NRZ data over 20 km of SMF using a 0.01 nm slice window [9], while classic 1.3 µm LED WDM experiments achieved only a few Mb/s per channel over ~2 km [10]. Overall, modern incoherent spectrum-sliced systems realistically achieve up to ~10 Gb/s over tens of kilometers (≈ 20–40 km), whereas simpler LED-based implementations typically remain in the low-Mb/s range over < a few km.

Table 1: Practical ASE / LED Spectrum-Sliced WDM Systems

| Ref | Source Type | Bit Rate per Channel | Number of Channels | Link Length | Notes / Comments |
|---|---|---|---|---|---|
| [7] | ASE | 40–50 Gb/s | 4–8 | ~2–3 km | Lab demonstration, ultrafast short link |
| [8] | ASE | 3 Gb/s | 32 | 40 km | SS-DWDM-PON projected design |
| [9] | SLED / LED | 10 Gb/s | 4 | 20 km | Ultra-narrow band Bessel slicing, practical lab |
| [10] | LED | few Mb/s | 4 | ~2 km | Classic early LED-based system |
| [4] | SLED | 10 Gb/s | 4 | 10–15 km | Lab test, practical for metro applications |
| [5] | SLED / ASE | 1–2 Gb/s | 8–16 | 5–10 km | Biomedical / OCT applications |

Not included in table 1 is work done by Chen *et al* [11]. Here, it was demonstrated that high-spectral-efficiency PDM-16QAM signals could be transmitted over 240 km of standard SMF-28 fiber using a sliced ASE source with self-coherent detection, showing performance comparable to conventional coherent systems. Its significance lay in proving a lower-cost, simplified coherent receiver architecture that reduces reliance on narrow-linewidth local-oscillator lasers while still supporting long-reach, high-capacity optical transmission.

Inherently in all spectrum slicing work utilizing incoherent sources is the intensity noise of within, as governed by the random spontaneous emission events, that poses a fundamental limitation to system performance [12]. This noise, often characterized by a relatively low signal-to-noise ratio (SNR), accumulates over fiber length due to attenuation, severely restricting the maximum achievable transmission distance [13]. The Semiconductor Optical Amplifier (SOA) has been widely studied as a compact and potentially integrable gain element for optical communication systems [14, 15]. Beyond mere amplification, when operated in the saturated regime, an SOA exhibits non-linear transfer characteristics that can compress the dynamic range of an input signal. This property can be harnessed to suppress the intensity noise inherent to incoherent sources, thereby improving the overall signal quality and, consequently, the system's Q-factor and Bit Error Rate (BER) performance.

In this paper, we demonstrate significant performance enhancement for a longer link length system than has previously been done in a 4-channel completely incoherent WDM system running at 10 Gb/s by integrating a single saturated SOA as a pre-amplifier and an extra filter on one channel. Section 2 introduces the idea, section 3 reports on the results, and conclusions are made in section 4

**Experimental set-up**

Four WDM channels were spectrally sliced, using ultra-narrow band-width Bessel filters, from a single broadband incoherent LED source at frequencies of 193.1, 193.2, 193.3 and 193.4 THz, corresponding to 1552.5, 1551.7, 1550.9 and 1550.1 nm, respectively. The channel spacing was 0.8 nm in the simulated single mode fiber link running at 10 Gb/s.

Figure 1 shows the baseline set up. There was no amplification in this link and the maximum link length achieved was 210 km, corresponding to the optical attenuation (fibre attenuation used was 0.2 dB/km) of 42 dB shown, before the average Q-factor achieved from all four channels reduced from around 8 to just above an acceptable value of 6.

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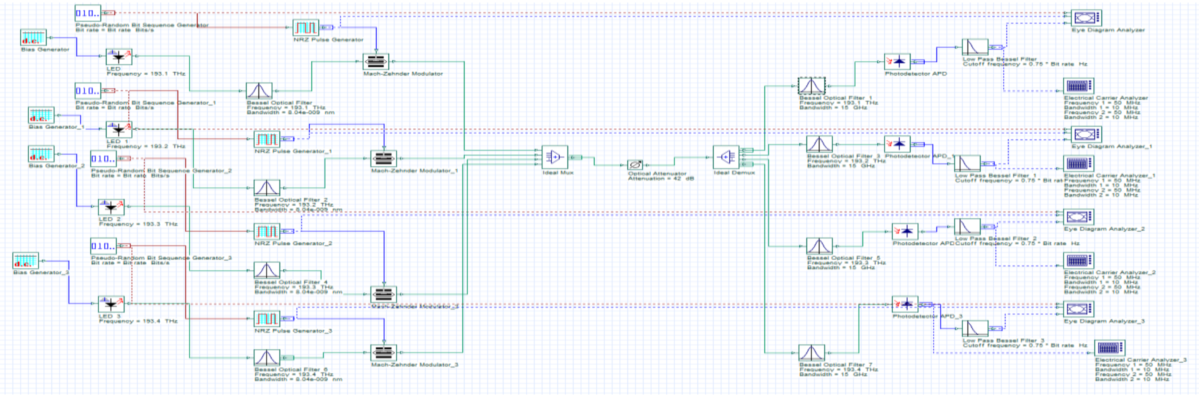


Figure 1: basic four channel WDM set-up used without SOA enhancement

An additional four Bessel filters, each set at 15 GHz bandwidth, recovered the signals to be analyzed for Q-factor and SNR using eye diagram and electrical carrier analyzers, respectively.

Figure 2 shows the second WDM set-up used with SOA enhancement, with a single SOA and an extra filter placed on the 193.1 THz arm of the WDM system:

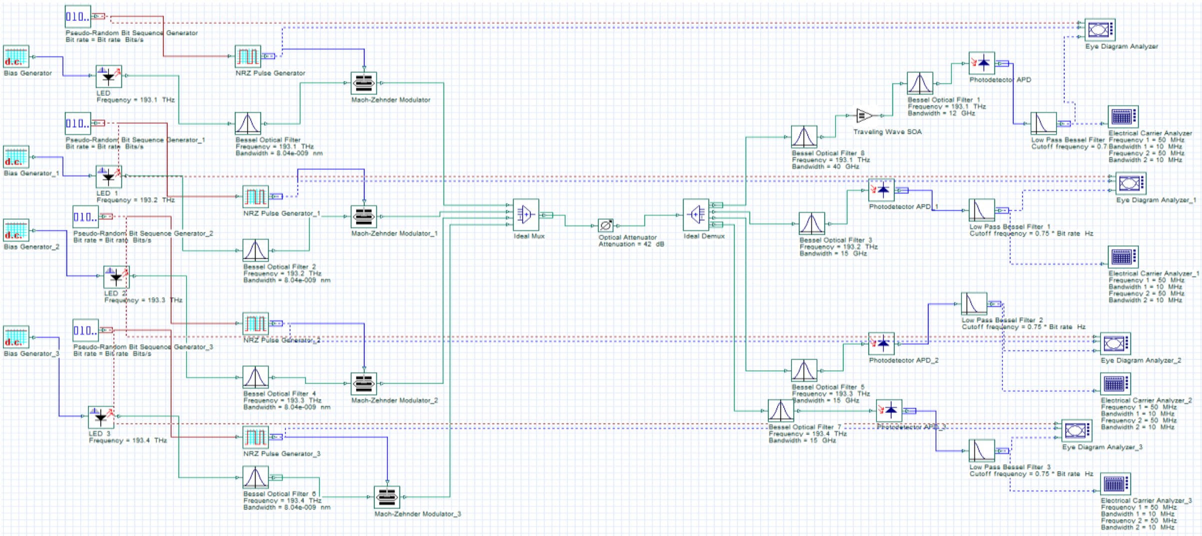


Figure 2: WDM set-up used with SOA enhancement

The extra Bessel optical filter bandwidth was set to 40 GHz, and the existing filter on the same arm was reduced to 12 GHz bandwidth for optimum effect. The SOA was also biased at 100 mA for optimum effect, and its input power was measured to be -24.6 dBm, representing partial saturation.

## RESULTS

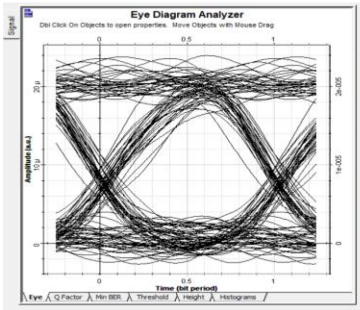
Table 2 shows results obtained on the Q-factors and SNRs received. It can be seen that the measured Q-factor with the SOA = 11.8, and the SNR with SOA = 66.7 dB, representing improvements of around 4.5 and a massive 51.6 dB, respectively.

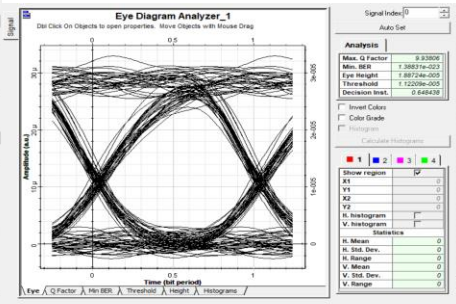
Table 2: Q-factors and SNRs received

| Frequency (THz) | Branch of circuit | Q - factors achieved without SOA | Q - factors achieved without SOA | SNRs (dB) achieved without SOA | SNRs (dB) achieved with SOA |
|---|---|---|---|---|---|
| 193.1 | Arm 1 | 7.3 | 11.8 | 15.1 | 66.7 |

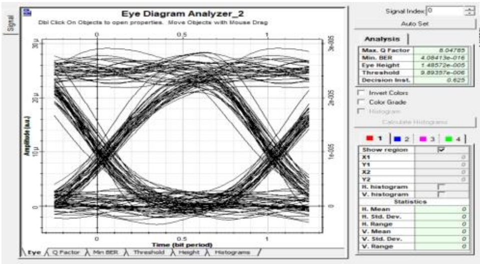
| | | | | | |
|---|---|---|---|---|---|
| 193.2 | Arm 2 | 9.9 | 9.9 | 14.9 | 14.9 |
| 193.3 | Arm 3 | 8.1 | 8.1 | 18.4 | 18.4 |
| 193.4 | Arm 4 | 9.6 | 9.6 | 18.4 | 18.4 |

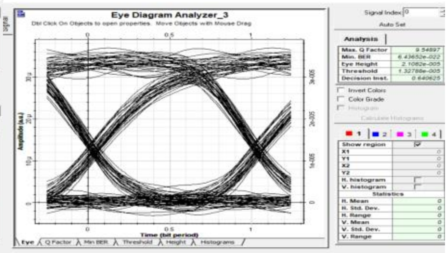
Figure 3 shows the eye diagrams obtained from the basic 4 channel link in figure 1:




(a) (b)




(c) (d)

Figure 3: eye diagrams obtained from each channel (a) 193.1 THz, (b) 193.2 THZ, (c) 193.3 THz, (4) 193.4 THz

These values are displayed in table 2. The average Q-factor obtained was around 8, and the average SNR was around 17 dB.

Figure 4 shows the improved eye diagram obtained with the SOA on arm 1 in the WDM system (from figure 2).

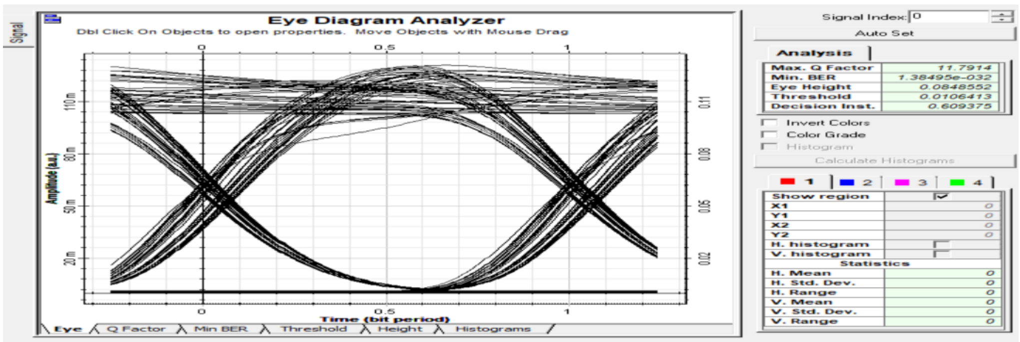



Figure 4: eye diagram obtained with the SOA on arm 1 in the WDM system

This was measured at 11.8, representing an improvement of 4.5 dB (as shown in table 2).

## CONCLUSIONS

The results obtained here have shown that the performance of a highly economical incoherent 4-channel completely spectrum-sliced WDM system can be considerably enhanced by incorporating a saturated semiconductor optical amplifier and an extra filter. The baseline system operating at 10 Gb/s over 210 km showed acceptable Q-factors and SNRs. However, the introduction of a single SOA placed on one channel yielded an acceptable 4.5 improvement in the measured Q factor and an exceptional improvement of almost 52 dB in the achieved signal-to-noise ratio (SNR), allowing an extra maximum of 130 km of link length travel - thereby extending the total reach of the enhanced channel to an unsurpassed 340 km. The results confirmed that a partially saturated SOA serves as a highly effective method for simultaneous amplification and intensity noise suppression, dramatically extending the reach and improving the signal integrity in an incoherent spectrum-sliced WDM system. Further work could vary the SOA input power to investigate optimum saturation effects, and test the benefits of putting an SOA on each of the 4 channels - but this would require extra, and therefore more costly, amplification. Overall, the simulation results reported here are perhaps a little more generous than practical optical systems, but they should assist designers of practical spectrum-sliced systems to produce more economical systems with much longer link lengths in the future, without sacrificing data rate.

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