

# A pulse amplitude modulation scheme based on in-line semiconductor optical amplifiers (SOAs) for optical soliton systems

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## ABSTRACT

The objective of this work is to simulate a pulse amplitude modulation (PAM) scheme based on in-line semiconductor optical amplifiers for optical soliton systems. The max. power for soliton systems, based on various bits/symbol PAM modulation schemes after a fiber length of 100 km, is simulated and clarified. In addition to the max. Q factor for soliton systems, PAM modulation schemes with various in-line SOA injection currents and a fiber length of 100 km are also simulated and demonstrated in the results. The total electrical power after photo-detectors for soliton systems, based on PAM modulation schemes with various in-line SOA injection currents and a fiber length of 100 km, is also simulated and clarified in the results. The study emphasizes that the higher the SOA injection current, the higher the electrical power and the lower the Q factor that can be achieved in the soliton system.

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## 1. RELATED WORKS

Networks operate at bit rates of the order of 100 Mb/s, due to optical media. Network standards with still higher bit rates (of the order of Gb/s) have been developed, e.g., fiber channel standard (FCS) and high-performance parallel interface (HIPPI) [1-8]. HIPPI uses multiple parallel links, each of which operates at bit rates of the order of 100 Mb/s [9-13]. The parallel links can use an electrical cable for shorter distances (a few meters) or optical fiber for longer distances (a few kilometers). Further increases in broadcast networks' capacity for efficient utilization of optical fiber have been hindered by an electronic bottleneck. Transmitters and receivers become extremely costly with an increase in bit rates above Gb/s [14-20].

At high bit rates, optical multiplexing and demultiplexing techniques are used to attain large-capacity networks. Large-capacity switched optical networks are also possible [21-28]. Soliton is an isolated, particle-like wave that offers a solution in certain equations for propagating and acquiring when two solitary waves do not change their form after collision and, subsequently, travel for considerable distances [29-35].

## 2. MODEL DESCRIPTION AND RESEARCH METHOD

Figure 1 shows the proposed soliton system, based on inline SOAs with pulse amplitude modulation technique. The user-defined sequence generators are responsible for the generation of bit streams. The bit stream sequences are modulated through an electrical PAM modulator. The optical Sech pulse generators are responsible for generating soliton pulses. The basic concept in soliton systems is the balance between dispersion effects and nonlinearity effects. The nonlinear effects are the reason for the pulse shrinking, but the dispersion effects are the reason for the pulse broadening. So, when the two effects are balanced, the result is a balanced soliton pulse that can be propagated for max. transmission distances.

The soliton pulse frequency is 193.1 THz with power of 100 mW. The LiNbO3 electro-optic modulators have three inputs: two electrical modulated signals and one soliton optical pulse. The electro-optic modulated signal is injected into the fiber length of 100 km. The signal power is measured through optical spectrum analyzers. The signal is amplified, and signal processing can be applied through traveling-wave SOA. The amplified signal is eliminated from the ripples through Gaussian light filters. The optical receiver is APD photo-detectors, which are responsible for converting light signals into electrical signal form. The total electrical power, max. Q factor, and min. BER can be measured through electrical power meter and eye diagram analyzers, respectively.

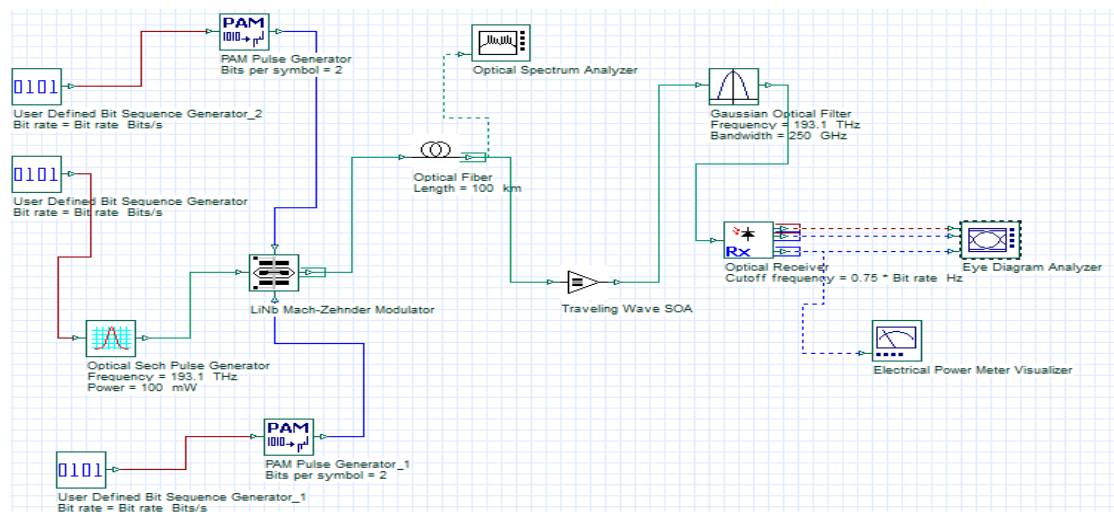


Figure 1. Proposed model description for this study

## 3. PERFORMANCE ANALYSIS WITH DISCUSSIONS

We have simulated the max. power for soliton systems based on various bits/symbol in a PAM modulation scheme after a fiber length of 100 km. Also, the max. Q factor for the soliton PAM modulation scheme is shown using in-line SOA, based on various injection currents at a fiber length of 100 km. Moreover, the total electrical power for the soliton PAM modulation scheme is demonstrated using in-line SOA based on various injection currents at a fiber length of 100 km. All the results are assured, based on the variable in Table 1.

Table 1. Basic parameters for proposed model

| Variables                  | Values/units  |
|----------------------------|---------------|
| Pulse frequency            | 193.1 THz     |
| Pulse power                | 100 mW        |
| Fiber length               | 100 km        |
| SOA injection current      | 30 mA- 100 mA |
| Modulator extinction ratio | 20 dB         |
| Modulator bias voltage     | 4 V           |
| Modulator insertion loss   | 5 dB          |
| Optical filter bandwidth   | 250 GHz       |
| Optical filter frequency   | 193.1 THz     |
| Optical receiver type      | APD           |
| APD gain                   | 10            |
| APD responsivity           | 0.9 A/W       |

Figures 2-6 show the max. power for soliton systems based on various bits/symbol in a PAM modulation scheme after a fiber length of 100 km. Figure 2 clarifies the max. power for a soliton system based on a 2 bits/symbol PAM modulation scheme after a fiber length of 100 km. Where the max. soliton power is -9.726 dBm, the noise soliton power is -104.299 dBm. Figure 3 indicates the max. power for a soliton system based on a 4 bits/symbol PAM modulation scheme after a fiber length of 100 km. Where the max. soliton power is -9.66482 dBm, the noise soliton power is -104.302 dBm. Figure 4 demonstrates the max. power for a soliton system based on an 8 bits/symbol PAM modulation scheme after a fiber length of 100 km. Where the max. soliton power is -9.25334 dBm, the noise soliton power is -104.321 dBm.

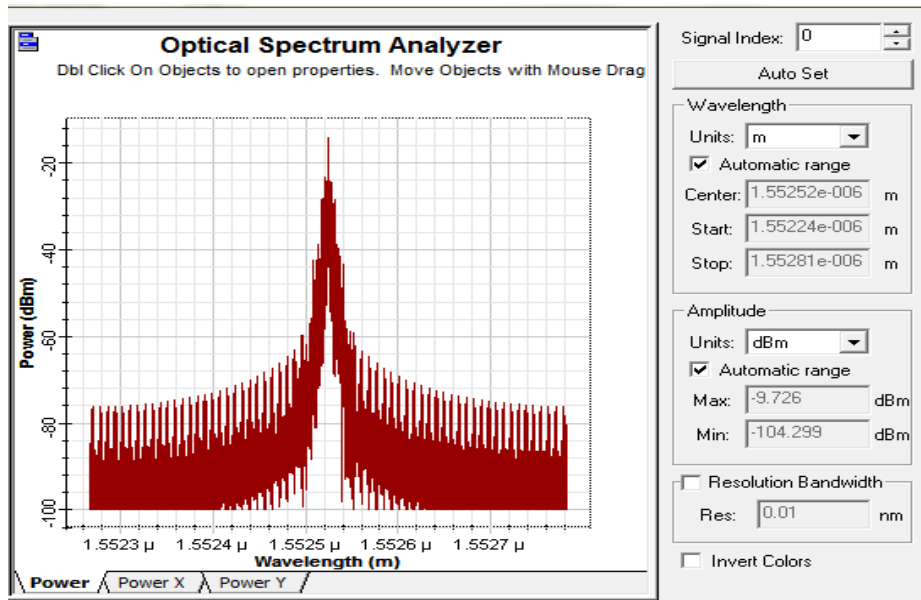


Figure 2. Max. power for soliton system based 2 bits/symbol PAM modulation scheme after fiber length of 100 km

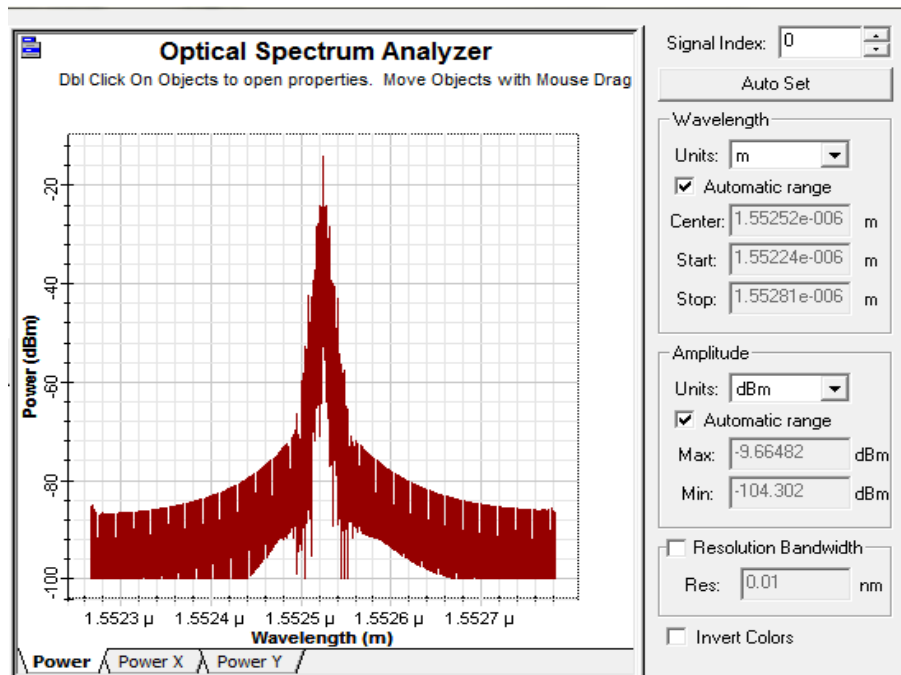


Figure 3. Max. power for soliton system based 4 bits/symbol PAM modulation scheme after fiber length of 100 km

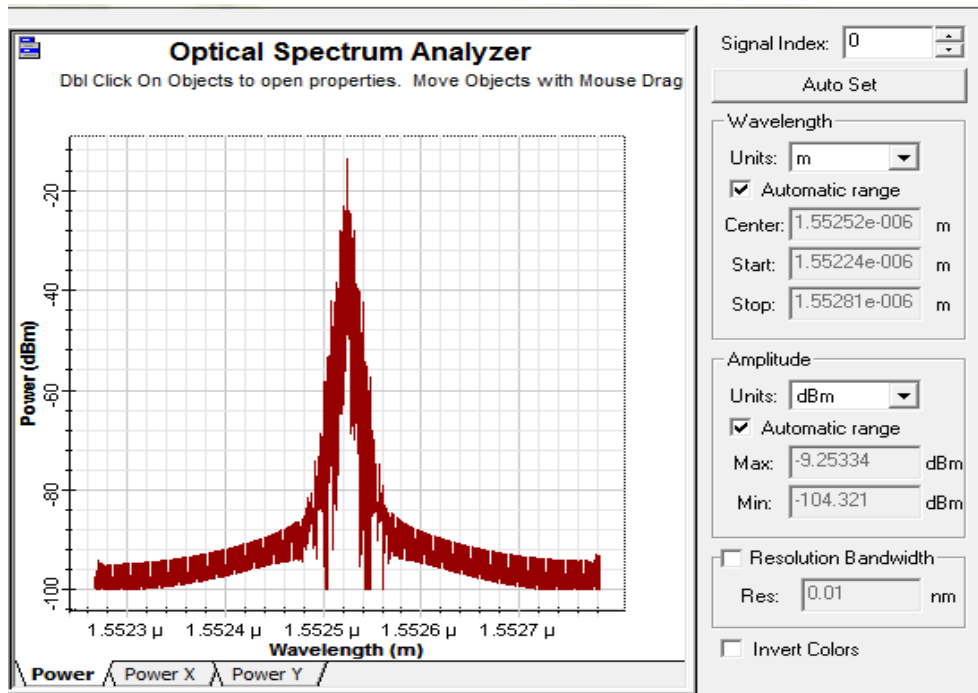


Figure 4. Max. power for soliton system based 8 bits/symbol PAM modulation scheme after fiber length of 100 km

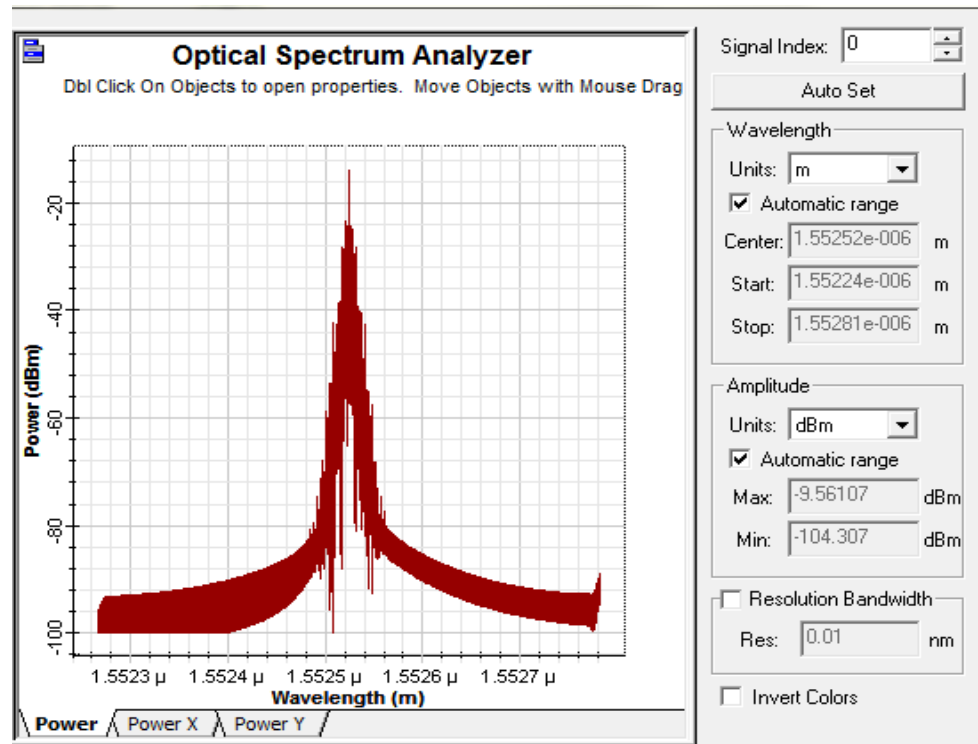


Figure 5. Max. power for soliton system based 16 bits/symbol PAM modulation scheme after fiber length of 100 km

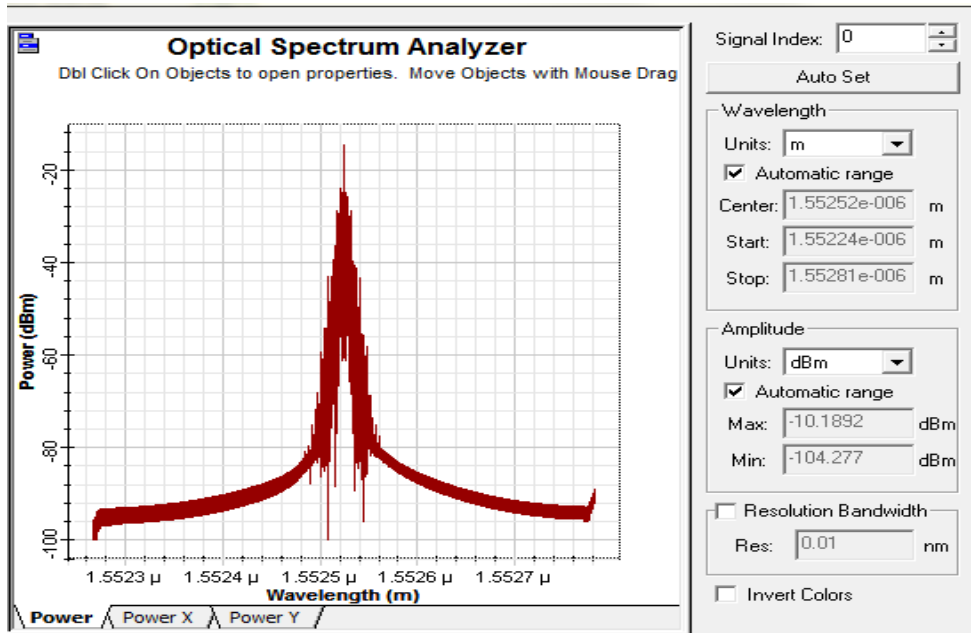


Figure 6. Max. power for soliton system based 32 bits/symbol PAM modulation scheme after fiber length of 100 km

Figure 5 shows the max. power for a soliton system based on a 16 bits/symbol PAM modulation scheme after a fiber length of 100 km. Where the max. soliton power is -9.56107 dBm, the noise soliton power is -104.307 dBm. Figure 6 illustrates the max. power for a soliton system based on a 16 bits/symbol PAM modulation scheme after a fiber length of 100 km. Where the max. soliton power is -10.1892 dBm, the noise soliton power is -104.277 dBm. The soliton peak power degrades with an increase of bits per symbol, based on the PAM modulation scheme. Figure 7 illustrates the max. Q factor for a soliton PAM modulation scheme based on an in-line SOA injection current of 30 mA and a fiber length of 100 km. Where the max. Q factor is 11.31, the min. BER is  $3.49 \times 10^{-30}$ . Figure 8 demonstrates the total electrical power for a soliton PAM modulation scheme based on an in-line SOA injection current of 30 mA and a fiber length of 100 km. The total electrical power is measured at a value of 2.556 mW (4.075 dBm).

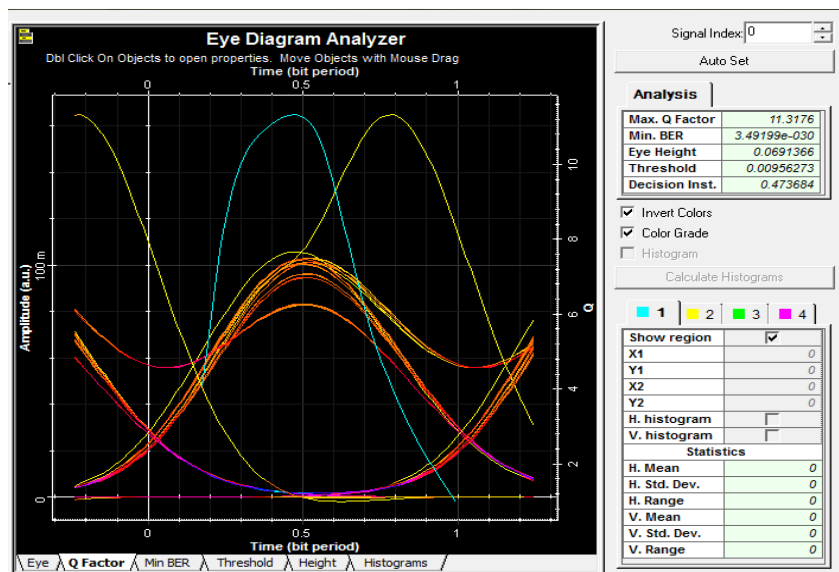


Figure 7. Max. Q Factor for soliton PAM modulation scheme based in line SOA injection current of 30 mA and fiber length of 100 km

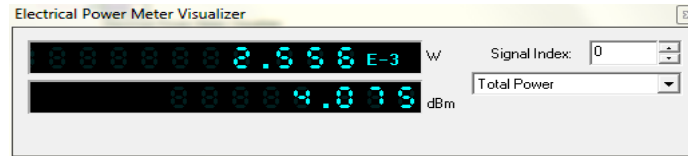


Figure 8. Total electrical power for soliton PAM modulation scheme based in line SOA injection current of 30 mA and fiber length of 100 km

Figure 9 shows the max. Q factor for a soliton PAM modulation scheme based on an in-line SOA injection current of 65 mA and a fiber length of 100 km. Where the max. Q factor is 9.24, the min. BER is  $1.105 \times 10^{-20}$ . Figure 10 illustrates the total electrical power for a soliton PAM modulation scheme based on an in-line SOA injection current of 65 mA and a fiber length of 100 km. The total electrical power is measured at a value of 51.009 mW (17.076 dBm).

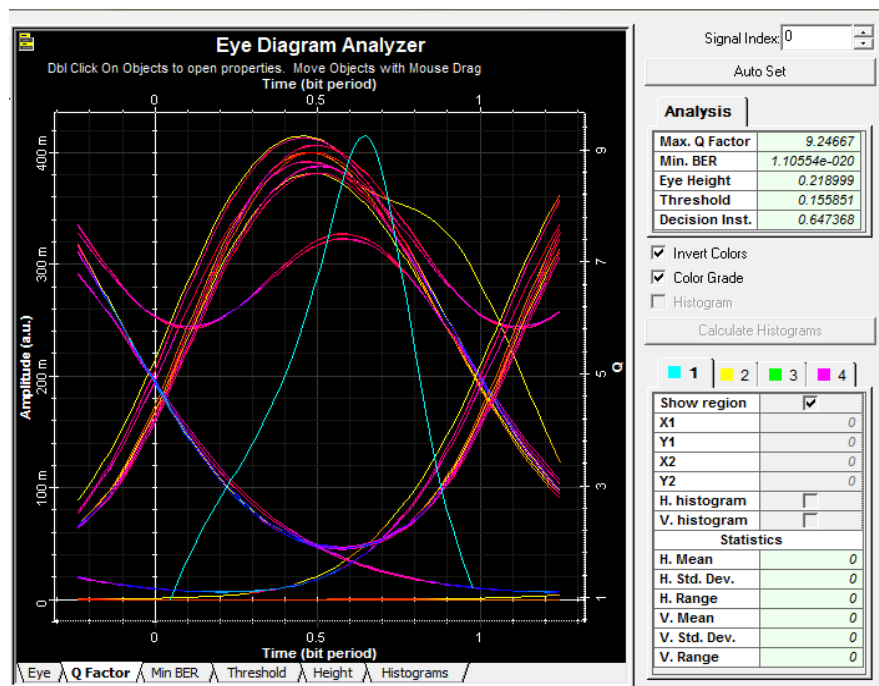


Figure 9. Max. Q Factor for soliton PAM modulation scheme based in line SOA injection current of 65 mA and fiber length of 100 km

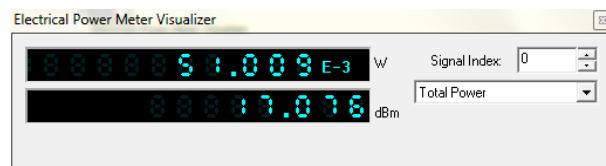


Figure 10. Total electrical power for soliton PAM modulation scheme based in line SOA injection current of 65 mA and fiber length of 100 km

Figure 11 shows the max. Q factor for a soliton PAM modulation scheme based on an in-line SOA injection current of 100 mA and a fiber length of 100 km. Where the max. Q factor is 5.97, the min. BER is  $1.142 \times 10^{-9}$ . Figure 12 indicates the total electrical power for a soliton PAM modulation scheme based on an in-line SOA injection current of 100 mA and a fiber length of 100 km. The total electrical power is measured at a value of 95.9 mW (19.818 dBm).

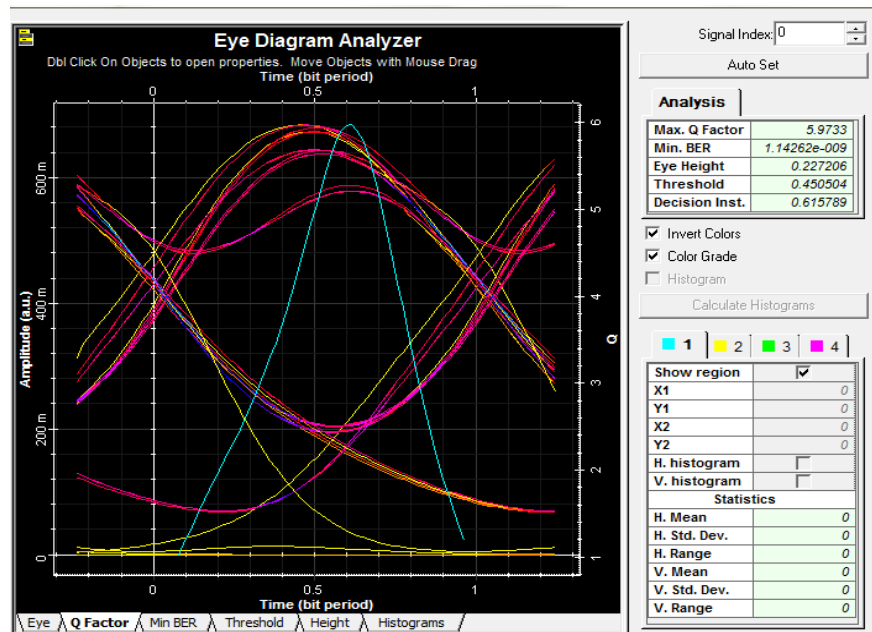


Figure 11. Max. Q Factor for soliton PAM modulation scheme based in line SOA injection current of 100 mA and fiber length of 100 km

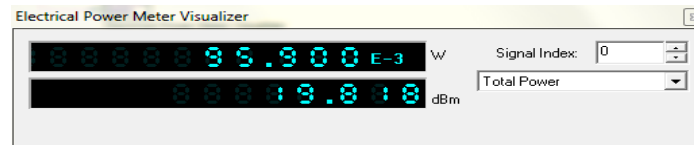


Figure 12. Total electrical power for soliton PAM modulation scheme based in line SOA injection current of 65 mA and fiber length of 100 km

#### 4. CONCLUSION

We have simulated the total electrical power for a soliton PAM modulation scheme based on an in-line SOA for various injection currents at a fiber length of 100 km. This work has demonstrated that the higher the SOA injection current, the higher the electrical power that can be achieved. Also, we have simulated the max. Q factor for the soliton PAM modulation scheme based on various in-line SOA injection currents at a fiber length of 100 km. The study shows that the lower the SOA injection current, the higher the Q factor that can be achieved. Moreover, the max. power for the soliton system has been clarified based on various bits per symbol PAM modulation schemes at a fiber length of 100 km. The results show that the lower the PAM modulation scheme's bits per symbol, the higher the soliton system power that can be achieved.

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