# Spectral gain measurement of extended L-band EDFAs using a saturating tone

**Firat Ertac Durak[1,2], Saber Jalilpiran[1], Kaboko Jean-Jacques Monga[1], Frédéric Maes[3], Lixian Wang[3] , Younès Messaddeq[1] and Sophie LaRochelle[1,*]**
[1]*Center for Optics, Photonics and Lasers (COPL), Université Laval, Québec, Canada*
[2]*on leave from Photonics Technologies Application and Research Center (FOTAM), Kütahya Dumlupınar University, Kütahya, Turkey*
[3]*Canada Research Center, Huawei Technologies Canada, Ottawa, Ontario, Canada*
**Author e-mail address: sophie.larochelle@gel.ulaval.ca*

**Abstract:** We compare the spectral gain measurement of an extended L-band EDFA performed using a saturation tone combined with a tunable signal, to the measurement done with an L-band comb source. The optimum tone wavelength is investigated.

## 1. Introduction

The improvement of the erbium-doped fiber amplifier (EDFA) performance at longer wavelengths, so as to extend the coverage of L-band amplifiers above 1620 nm, paves the way to a higher data transmission capacity in optical communication systems [1-2]. The development of extended L-band EDFAs requires characterization techniques to measure spectral gain and noise figure (NF) accurately up to at least 1626 nm. Such measurement methods for the characterization of EDFA gain and NF are well-established in C-band. Accurate gain shape characterization of EDFAs in scenarios representative of wavelength division multiplexing (WDM) systems can require a large number of optical sources to saturate the amplifier and measure gain and NF adequately. Several approaches have been proposed in the literature to reduce the laser source requirement. Gain characterization of C-band EDFA can be done with a reduced set of saturating channels instead of a large number of WDM channels, for example using four saturating tones in the C-Band [3]. In [4], comparaison of EDFA gain measurement was performed between test results obtained under a fully loaded input condition with 31 WDM channels, and the measurement done using saturation tone signals (1530 nm or 1555 nm) combined to a small signal probe. In this paper, we address the gain characterization of extended L-band EDFAs for which equipment is less readily available in many laboratories. More precisely, we use an 8-channel comb source covering from 1573 nm to 1626 nm to characterize the spectral gain. We compare the results to spectral gain measurements with a single saturation tone in an alumino-phosphosilicate erbium-doped fiber (EDF). We discuss the impact of the saturating tone wavelength on the fit between the two measurement techniques.

## 2. Experimental Setup

The experimental setup for extended L-band EDFA characterization is shown in Fig. 1. An EDF fabricated in-house using a conventional MCVD process, with the solution doping, was optimized to provide gain up to, and beyond, 1620 nm. The EDFA was bi-directionally pumped with 980 nm laser modules in both scenarios, each pump power was 800 mW and an optical spectrum analyzer (OSA) recorded the signals. A 3-dB coupler was inserted after WDM-2 to reduce the input power at the OSA.

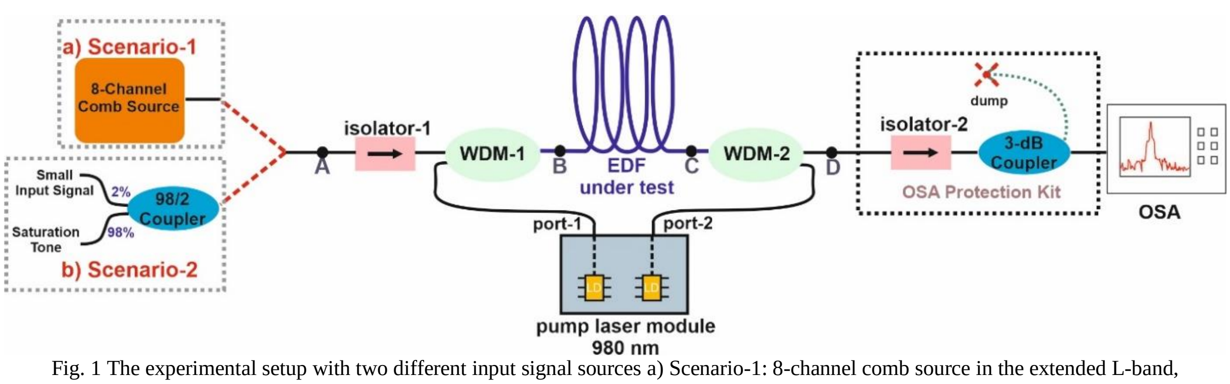


Fig. 1 The experimental setup with two different input signal sources a) Scenario-1: 8-channel comb source in the extended L-band, b) Scenario-2: Saturation tone with a tunable probe signal.

In the first scenario, an 8-channel comb source is used as the input signal source to the amplifier with a total input signal power set to 1.3 dBm (the power is equally divided among all channels). Also, the wavelength distribution of the comb-source was adjusted to be equally spread in the frequency domain between 1573 nm to 1626 nm. In the second scenario, we used two tunable laser sources, one as a probe with a small input signal power and one as a saturation tone. Firstly, the saturation tone signal power was fixed to 1.3 dBm, and the probe power was -31 dBm. To find the optimum wavelength for the saturating tone, its wavelength was changed between 1575 nm to 1620 nm. Afterwards, we repeated the experiment by changing the saturation level of the amplifier using input signal power of 0 dBm and -5 dBm. It should be mentioned that all reported gain measurements are internal values, which means that the calculation was done between point-B and point-C.

## 3. Experimental Results and Discussion

The comparison of the gain measurement performed with both scenarios is shown in Fig. (a), where the measurement performed with the 8-channel comb is shown as the solid blue dots/line. It can be seen that the saturating tone wavelength of 1596 nm provides the best match to the 8-channel comb measurement, with a gain difference smaller than 0.35 dB over the wavelength band from 1575 nm to 1626 nm. A small discrepancy between both measurements is mainly observed for wavelengths shorter than 1596 nm. Saturation wavelengths shorter than 1596 nm tends to overestimate the gain, while saturation wavelengths longer than 1596 nm tend to underestimate it (except for 1620 nm). In Fig. (b,c,d), the gain measurement for both scenarios is illustrated for different saturation levels of the EDFA with total input powers of 1.3 dBm, 0 dBm, and -5 dBm. Results show that the saturation tone of 1596 nm still provide an excellent fit to the 8-channel comb measurement. Note that this saturating tone wavelength is 3.5 nm shorter than the middle point of the considered L-band wavelength range (1575 nm to 1626 nm) that was previously proposed in [3].

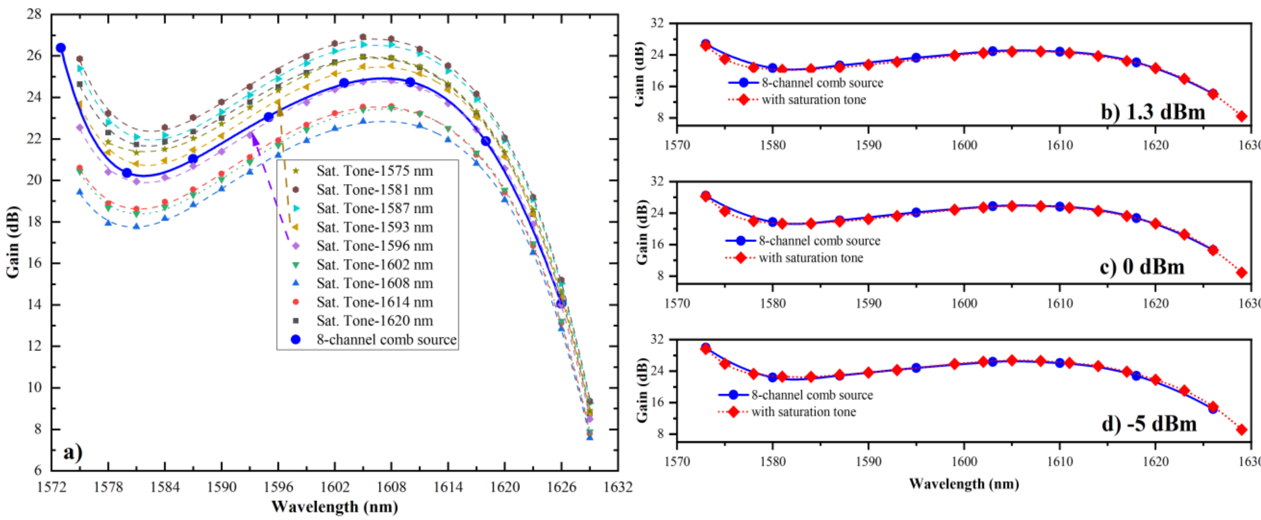


Fig. 2. Spectral gain measurement of L-Band EDFA with both measurement techniques. a) Measurement as a function of input signal wavelength for a saturation tone input power fixed to 1.3 dBm. Gain measured at different EDFA saturation level using a saturating tone power of b) 1.3 dBm, c) 0 dBm and d) -5 dBm, respectively.

## 4. Conclusion

In this study, we have proposed an effective solution to the characterization of EDFA that replaces wavelength-multiplexed optical sources by a saturation tone and a tunable small signal. An excellent fit of the spectral gain shape of an L-Band EDFA was experimentally achieved over an extended wavelength band up to 1626 nm.

## 5. References

[1] B. J. Puttnam, R. S. Luís, G. Rademacher, Y. Awaji and H. Furukawa, "319 Tb/s Transmission over 3001 km with S, C and L band signals over >120 nm bandwidth in 125 µm wide 4-core fiber," 2021 Optical Fiber Communications Conference and Exhibition (OFC), paper F3B.3 (2021).
[2] Y. Lou, *et al*., "Er3+/Ce3+ Co-doped Phosphosilicate Fiber for Extend the L-band Amplification," *J. Lightwave Technol*. **39**, 5933-38 (2021).
[3] D. M. Baney and J. Stimple, 'WDM EDFA Gain Characterization with a Reduced Set of Saturating Channels', *IEEE Photon. Techol. Lett*. **8** (1996).
[4] P. F. Wysocki, 'Broadband Amplifier Measurement Techniques', OSA Trends in Optics and Photonics, (2000).