OFDM Transmission using a Self-seeded ring Cavity based on a Semiconductor Optical Amplifier

Raed El Hassanieh†,§,*, Pascal Morel†,*, Mohamad Hamze§,*, Véronique Quintard†, André Pérennou†, Ammar Sharaiha†

† Ecole Nationale d'Ingénieurs de Brest (ENIB), CNRS, UMR 6285 Lab-STICC, 29238 Brest, France.

§ Arts Sciences and Technology University in Lebanon (AUL), Cola, Beirut, Lebanon.

* Email: raed.al-hassanieh@enib.fr, morel@enib.fr, mohamad.hamze@aul.edu.lb.

***Abstract* – This paper discusses the transmission of optical Orthogonal Frequency-Division Multiplexing (OFDM) format modulation in a resonant cavity based on a Semiconductor Optical Amplifiers Fiber Cavity Laser (SOA-FCL). The OFDM Sub-carriers are configured and transmitted to fit the Cavity Resonance Modes (CRM). As a result, the authors show a novel principle of OFDM transmission in a self-seeded cavity, which reduces the Error Vector Magnitude.**

***Index terms* - Orthogonal Frequency-Division Multiplexing - Subcarriers - Semiconductor Optical Amplifiers Fiber Cavity Laser - Cavity Resonance Modes - Error Vector Magnitude.**

I. Introduction

The exponential increase in end-users and the huge demand for high data rate transmission have urged researchers to conduct studies on self-seeded cavities. These cost-efficient cavities are considered colorless, self-tuning, and self-seeded sources [1], [2].

In our recent work, some advantages were shown in the one-way cavity structure (stability and noise level) [3]. According to the finding, we pursue our study for data transmission on the mentioned cavity.

It is known that when using a self-seeded structure, Cavity Resonance Modes (CRM) appear with a frequency of equal spacing and they are calculated through the cavity length and the refractive index of the fiber [4]. Based on these features, we assumed that the Orthogonal Frequency Division Multiplexing (OFDM) could be suitable for data transmission based on the CRM since OFDM promotes resilient communications through low-rate data in multiple equally-spaced carriers that are orthogonal to each other [5]. This paper presents the principle and the characterization of the OFDM transmission through the one-way self-seeded cavity. The influence of data rate and the position of OFDM sub-carriers (SC) are studied by simulation.

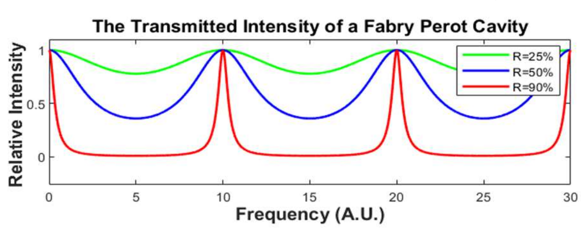

Fig. 1. Cavity Resonance Modes with respect to the mirror's reflectivity.

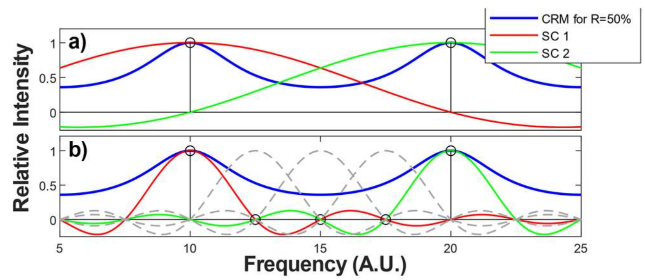

Fig. 2. a. Two consecutive OFDM SCs are located on the CRMs.
b. Three additional SCs without data (dashed line) are added between the CRMs.

II. OFDM Transmission In A SOA-FCL

In a Semiconductor Optical Amplifiers Fiber Cavity Laser (SOA-FCL), the resonant cavity is characterized by the Free Spectral Range (FSR). The FSR is the frequency separation between two consecutive CRM depending on the cavity length. Then the finesse F of the CRM is given by $F = \frac{FSR}{\Delta\nu}$ which is inversely proportional to the Full-Width Half-Maximum (FWHM) spectral width ($\Delta\nu$). Fig. 1 represents the influence of the reflection coefficient R of the cavity mirrors for a fixed cavity length on the transmitted intensity of a resonant cavity (Fabry-Pérot). It identifies that, when the reflectivity of the mirrors increases, $\Delta\nu$ decreases, and accordingly F increases leading to higher selectivity of the CRM [6].

OFDM transmission is a multicarrier modulation that consists of several enclosed and equally-spaced modulated carriers. Using OFDM with a resonant cavity can bring good transmission when the OFDM SCs are configured to be located and fit the CRM as shown in Fig. 2.

In Fig. 2. a. the SC does not completely encompass the CRM whereas in Fig. 2. b. additional SCs are added without data making it possible to reduce the frequency bandwidth of all the SCs leading to higher data power transmission.

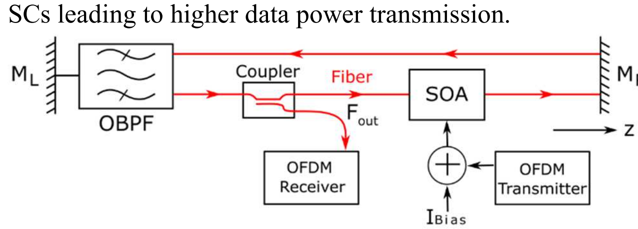

Fig. 3. Principle setup for one-way cavity with OFDM transmitter and receiver.

III. Simulation And Results

Fig. 3 shows the cavity structure of the used time-domain model of the SOA-FCL where the optical field propagates only in one direction through the SOA. This time-domain model allows the analysis over a wide optical bandwidth reaching a time scale of pico-second [7]. This optical field is generated by the SOA from the Amplified Spontaneous Emission (ASE) which propagates inside the cavity and gets amplified at each round trip. To select a given laser wavelength range, an Optical Bandpass Filter (OBPF) is inserted inside the cavity, eliminating the white noise obtained from the ASE and keeping a window for the laser to be formed. Each mirror inside the cavity has a reflectivity of 50%. After several round trips, the laser is established and the cavity reaches its steady state.

To implement the OFDM, the Intensity-Modulation Direct Detection (IMDD) system is used to generate a real, positive output from the transmitter [8]. Some features of the IMDD are its low computational complexity and low cost in optical communication systems. A real signal can be applied to modulate the intensity (or amplitude) of an optical signal straightforwardly either by using an intensity modulator or by modulating the laser directly. To generate a real output from the transmitter, researchers apply the Hermitian symmetric method. Meanwhile, the OFDM signal is modulated with the SOA bias current (I_{Bias}) to create a positive (non-negative) output.

To transmit data through the one-way cavity, OFDM SCs with data are configured to be sent on the CRMs as in Fig. 2a.

For better transmission, different configurations were tested for the OFDM frame construction to fit each SC data bandwidth to the CRM bandwidth as shown in Fig. 2b. The number of the SC is adjusted according to the cavity's finesse. In other words, the number of SCs are increased and only the SCs located on the modes will contain data.

Table I shows three different configurations of OFDM data transmission that were tested through MATLAB. These configurations were based on the FSR (10.197 MHz) calculated from the one-way cavity length of L=10 m. In the three cases, 112 SCs per Symbol were used for 4-QAM data modulation and sent based on the CRM. However, in the 2nd and 3rd case, one and three SCs respectively were added without data between the mode to decrease the SCs bandwidth. The first two symbols on the OFDM frame represent the preambles and then in every OFDM data symbol, eight pilots were used. The bandwidth of the OFDM signal is 1.305 GHz, resulting from the number of SCs multiplied by the SC frequency separation.

Fig. 4 presents the Error Vector Magnitude (EVM) and the constellation diagrams measured after the OFDM receiver. The EVM value decreased by around 10 % between the 1st and 3rd case. Also, the constellation diagrams show a considerable improvement when decreasing the SC bandwidth to fit the resonance peak of the cavity.

Table I. Transmission Parameters with OFDM Bandwidth of 1.305 GHz, Sampling Rate 11.747 GHz, and 16 Symbols/Frame for a 10m cavity.

Parameter	**Case1**	**Case2**	**Case3**
Number of SC per symbol	128	256	512
SC Freq. Separation (MHz)	10.197	5.098	2.549
Data bit rate for 4-QAM (Gb/s)	2.0	1.0	0.5
Ratio of data SC over SCs in one mode	1/1	1/2	1/4

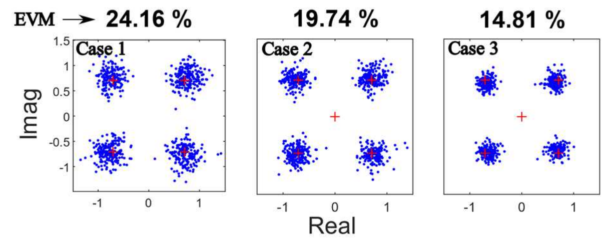

Fig. 4. Constellation diagram and EVM results for the 3 cases presented in Table I.

IV. Conclusion

The paper shows that the one-way cavity architecture could be used for data transmission by using OFDM especially when the SCs are sent on the CRMs. Primary results show a decrease of around 10% in the EVM when changing the OFDM SCs configuration to fit the CRMs. This behavior is confirmed by experimental measurements.

Acknowledgment

This work was supported by the "Conseil Départemental du Finistère", "Brest Metropole" (France), ENIB and by "AUL University" (Lebanon).

References

[1] S. Gebreworld, et al. “Reflective-SOA Fiber Cavity Laser as Directly Modulated WDM-PON Colorless Transmitter,” *IEEE J. Quantum Electron.,* vol. 20 (5), September/October 2014.

[2] F. Saliou, et al. “125-km Long Cavity Based on Self-Seeded RSOAs Colorless Sources for 2.5-Gb/s DWDM Networks,” *J. Lightw. Technol.,* vol. 33 (5), April 2015.

[3] R. El Hassanieh et al., "Time Domain Numerical Study of Two Semiconductor Optical Amplifiers Laser Cavity Structures," *2021 International Conference on Numerical Simulation of Optoelectronic Devices (NUSOD)*, 2021, pp. 123-124, doi: 10.1109/NUSOD52207.2021.9541528.

[4] A. Maho et al., "Demystification of the Self-Seeded WDM Access," in *Journal of Lightwave Technology*, vol. 34, no. 2, pp. 776-782, 15 Jan.15, 2016, doi: 10.1109/JLT.2015.2466090.

[5] J. Armstrong, "OFDM for Optical Communications," in *Journal of Lightwave Technology*, vol. 27, no. 3, pp. 189-204, Feb.1, 2009, doi: 10.1109/JLT.2008.2010061.

[6] G. Gagliardi and H.-P. Loock, Cavity-Enhanced Spectroscopy and Sensing. New York, NY, USA: Springer, 2014.

[7] P. Morel, and A. Sharaiha, “Wideband Time-Domain Transfer Matrix Model Equivalent Circuit for Short Pulse Propagation in Semiconductor Optical Amplifiers,” *IEEE J. of Quant. Electronics,* vol. 45 (2), pp. 103-116, February 2009.

[8] N. E. Jolley et al., "Generation and propagation of a 1550 nm 10 Gbit/s optical orthogonal frequency division multiplexed signal over 1000m of multimode fibre using a directly modulated DFB," *OFC/NFOEC Technical Digest. Optical Fiber Communication Conference*, vol. 6, pp. 3, 2005