OSSB-OFDM TRANSMISSION PERFORMANCE USING A DUAL ELECTROABSORPTION MODULATED LASER IN NG-PON CONTEXT

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ABSTRACT

We report system simulation and experimental results on enhanced transmission distance over standard single mode fiber thanks to a novel dual modulation technique that generates a wideband optical single side band orthogonal frequency division multiplexing (OSSB-OFDM) signal using a low-cost, integrated, dual RF access electro-absorption modulated laser. We obtained in experimentation and by simulation a bit error rate (BER) lower than 10^{-3} for 11 Gb/s up to 200 km in an amplified point-to-point configuration for an optical single side band discrete multi-tone (OSSB-DMT) signal. We also experiment in simulation conventional OFDM at 25 Gb/s in point-to-multipoint architecture and we show that the transmission reach can be extended to 55 km for a BER at 10^{-3} thanks to the new technique we have developed and implemented.

Index Terms— Optical Communications; Optical Sources

1. INTRODUCTION

Next generation passive optical networks (NG-PON) will have to cope with the relentless bandwidth demand increase, the number of connected customers and the spreading of networks. The normalization institutions, like ITU-T and FSAN, seem to focus today on hybrid time and wavelength division multiplexing/multiple access options for the NG-PON. However, research continues in order to provide competitive alternatives, generally based on high-spectral efficiency modulation formats and/or high-efficiency transceivers. Their special interest is to reduce high-speed migration costs by preserving the actual optical distribution network infrastructure. In this paper, we propose to use both advanced modulation format and specific transceiver to increase bit rate and transmission distances in PON architectures (access and metropolitan) without any chromatic dispersion compensation.

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For nearly twenty years, the OFDM technique has been the focus of numerous studies in the field of optical telecommunication because it allows increasing the spectral efficiency of the modulated signal and offers better resistance to the chromatic dispersion effects due to the easy equalization process [1]. Despite these benefits, OFDM for intensity modulation - direct detection (IM-DD) channel is still penalized by chromatic dispersion effects occurring during the propagation which produce frequency-dependent fading, due to the interactions of the two side bands of the modulated optical signal. To solve this issue, a well-known solution is to suppress one of the two side bands of the modulated optical signal thereby producing optical single side band (OSSB) signal. Several techniques can be used to achieve OSSB condition like optical filtering or the use of dual parallel Mach-Zehnder modulator (DPMZM).

Kim Hoon *et al.* introduced the dual modulation of an integrated, directly modulated, distributed feedback (DFB) laser and electro-absorption modulator (EAM) as another solution to generate OSSB signal [2]. This technique is based on the controlled mixing of optical amplitude (AM) and frequency (FM) modulation [3]. Using this principle, encour-

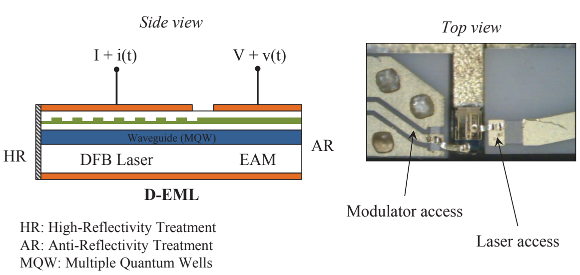

Fig. 1. Schematic and photography of the D-EML.

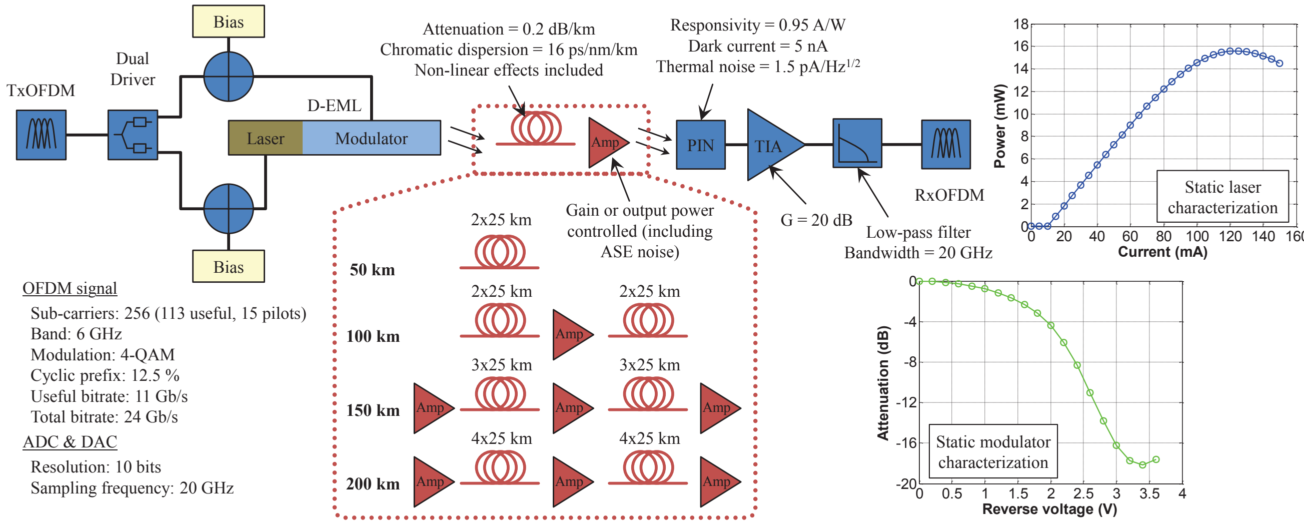

Fig. 2. Synoptic of the simulated link for DMT with main simulation parameters as well as the static characteristics of the D-EML (laser and modulator).

aging results have already been obtained with on-off keying non-return to zero modulation [4–6]. With this modulation format, we obtained results at the state of the art with a key component called dual electroabsorption modulated laser (D-EML). It consists of a monolithically integrated, dual RF access EML developed by III-V Lab.

In this paper we investigate a higher spectral efficiency modulation format with OFDM. We particularly focused on the transmission of a wideband OSSB-OFDM signal generated thanks to a technique we developed and present here. Performance has been assessed by experimentation and simulation. The first paragraph introduces the optical source used, its operation principle and the model we developed for system simulations. Then we report simulation and experimental results for discrete multi-tone (DMT) which use the Hermitian symmetry to make the baseband signal real for directly modulating the component. Moreover, experimental transmission results validate by comparison both the developed model of the original optical source and the system simulation method that we implemented. In the last section, system simulations at higher bit rate are also presented with conventional OFDM using RF carrier to make the baseband signal real.

2. COMPONENT, OPERATION PRINCIPLE AND MODELING

The D-EML is an optical source composed of a 470 µm-DFB laser and a 70 µm-EAM monolithically integrated on InP (Fig. 1). It emits in C-band at 1536 nm. The technology used is based on AlGaInAs multiple quantum wells (MQW) material for its large electronic confinement providing enhanced electro-absorption properties and reduced thermal carrier leakage. The same active layer is used for both laser and modulator section and their respective bandgaps were engineered by selective area growth. The DFB laser section is designed to improve the FM efficiency with respect to standard EML. The -3 dB FM-bandwidth of the laser is around 15 GHz and the -3 dB AM-bandwidth of the modulator is close to 30 GHz. Such a design completely separates optical FM and AM by applying digital or analog modulation respectively on the high FM-index laser section and on the high AM-index modulator section. Residual AM from the laser is negligible compared to AM produced by the modulator. Furthermore, it can be shown that adjusting the proportion and the phase of AM/FM for a complete frequency bandwidth, *i.e.* an OFDM signal, allows generating a wideband OSSB signal [3]. For an ideal FM/AM emitter the two modulations have to be either 0 or π phase shifted and the SSB condition can be expressed as a function of the peak-to-peak frequency deviation (Δf_{pp}) and intensity modulation index (m_{IM}) for each frequency (f)

$$\Delta f_{pp}(f) = m_{IM} f. \tag{1}$$

A realistic model of the D-EML has been developed from experimental characterization data. The laser model of D-EML is designed to use typical datasheet parameter values of the wavelength, linewidth, relative intensity noise, driver transconductance, electrical bandwidth, Henry's factor α_H (transient chirp), adiabatic chirp factor, optical efficiency, threshold current and optical output losses due to fiber coupling. This model takes into account the optical power saturation at high current, which is due to the fall of the gain and the increase of internal losses induced by the temperature increase. This has been particularly taken into account in order to include the non-linear effects which could reduce the OFDM transmission performances by affecting peak to average power ratio. The EAM model of the D-EML is based on

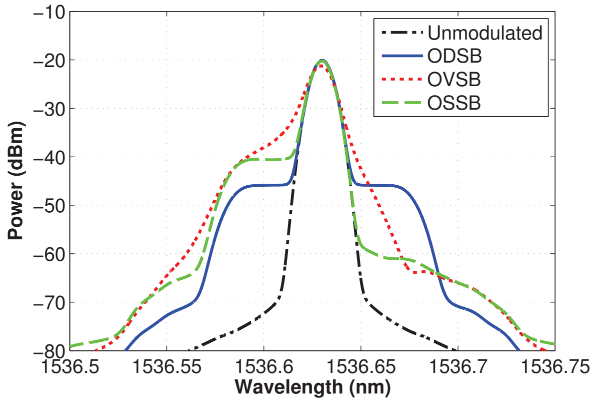

Fig. 3. Simulated optical spectra at the D-EML output for the three modulation configurations (resolution 10 pm).

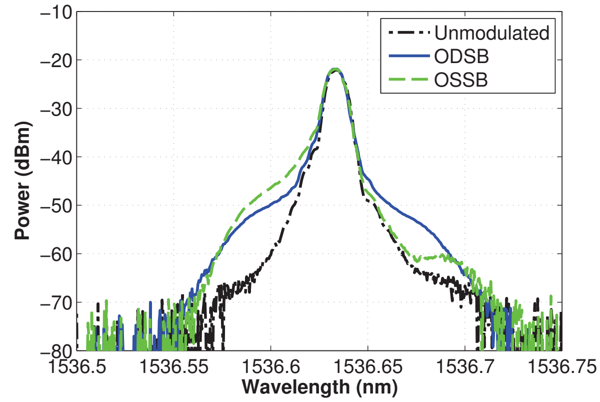

Fig. 4. Measured optical spectra at the D-EML output (resolution 10 pm).

a voltage-dependent polynomial approach to model the absorption function and Henry's factor variations. However the absorption function is wavelength-independent. As for the laser model, the electrical bandwidth effects are introduced by the means of electrical filter. The two inset graphs in Fig. 2 depict the laser and modulator static transfer characteristics.

3. EXPERIMENTAL AND SIMULATION RESULTS FOR A POINT-TO-POINT LINK

DMT uses Hermitian symmetry to produce real-valued electric signal after only one digital to analog converter. This technique allows reducing the complexity of emitter and receiver but the bit rate is twice lower than conventional OFDM. The Fig. 2 depicts the simulated link, which also corresponds to the experimental one, and the main parameters of the DMT signal. The D-EML is modulated by the 6 GHz bandwidth DMT signal through the dual driver that controls precisely, within a limited frequency band, the amplitude and phase of the two signals driving the laser and modulator. This driver acts as a digital filtering (magnitude and phase) in order to satisfy the SSB condition for a specific frequency or for a large bandwidth (15 GHz) depending on the set of coefficients used. These coefficients are the result of an optimization process. The laser is biased at 90 mA to give high optical output power without operating in the full non-linear area of its characteristic. Actually, the modulation amplitude applied on the laser remains relatively low. The EAM is biased at -2 V to obtain output power enough and amplitude modulation depth rightly. Different amplification schemes have been used for the evaluated distances from 50 km to 200 km. At the receiver side, a photodetector (PIN) and its transimpedance amplifier (TIA) of 20 GHz passband operates the optical to electrical conversion.

Three modulation schemes have been studied in simulation. In the first one, only the modulator is driven by the DMT signal. This single modulation produces optical double side band (ODSB) signal. In the second one, the proportion of AM/FM is optimized for only a specific frequency. This dual modulation scheme produces optical vestigial side band (OVSB) signal. In the third scheme, the SSB condition is satisfied within the whole frequency band 0 GHz-15 GHz leading to the generation of optical single side band (OSSB) signal. Fig. 3 shows the optical spectrum at the D-EML output when it is unmodulated and for the three previously described configurations. As it is shown in this figure, the achievement of the SSB condition for a large frequency band is necessary to obtain a good side band power ratio (SBPR) over the whole DMT signal band. The SBPR is defined as the absolute difference between the power of the lower and the upper side band. In simulation we obtained SBPR close to 20 dB over 6 GHz bandwidth for the OSSB operation.

As a comparison, the Fig. 4 depicts the measured optical spectra at the D-EML output for ODSB and OSSB configurations in the experiment. The OSSB configuration is here achieved by satisfying the SSB condition for only a specific

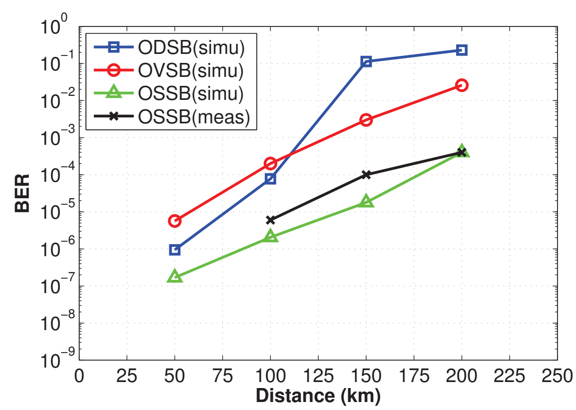

Fig. 5. BER versus distance at 11 Gb/s for the three configurations in simulation and for measured OSSB configuration.

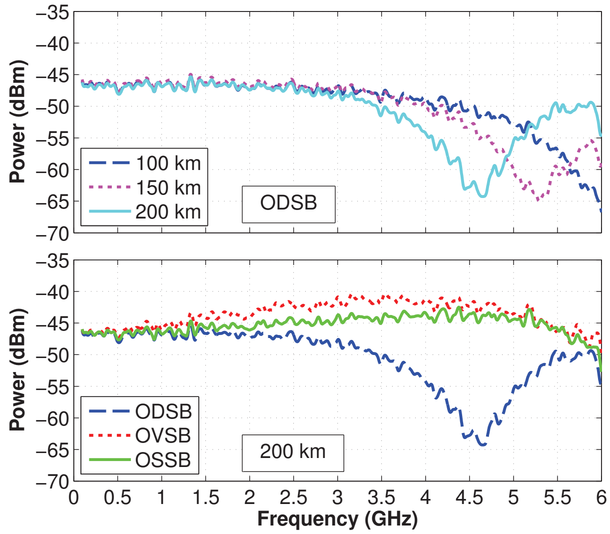

Fig. 6. Simulated electrical spectra after receiver in ODSB configuration for different distances (top) as well as in the three configurations ODSB, OVSB and OSSB at 200 km (bottom).

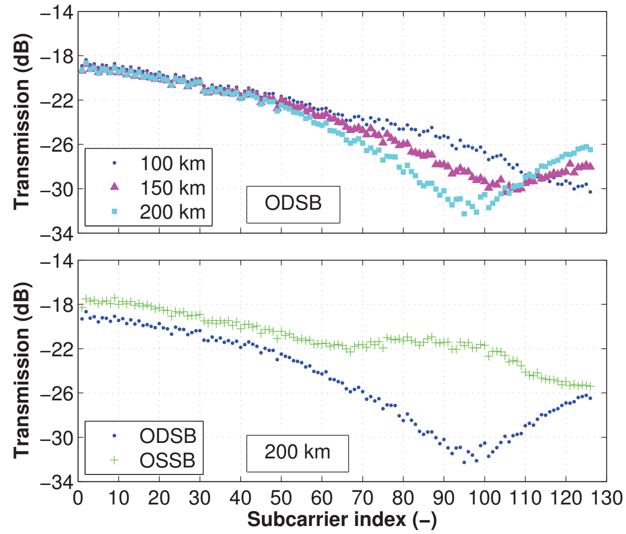

Fig. 7. Measured channel response versus DMT subcarriers (*i.e.* frequency) in ODSB configuration for different distances (top) as well as in ODSB and OSSB configurations at 200 km (bottom).

frequency. The electrical components that are used to realize the driving are frequency dependent (attenuator and delay line instead of digital filters). They lead the experiment to be closer to OSSB simulation case than OVSB one. The measured SBPR is about 10 dB which is twice lower than the simulated one because of the higher difficulty to optimize the SSB condition in experimentation (the use of digital filters in experimentation is in progress).

The bit error rate (BER) has been evaluated at 11 Gb/s versus the transmission distance as it is shown in Fig. 5. In simulation the BER for a M-QAM is inferred from the symbol error rate (SER) with the equation: $BER = SER/log_2(M)$. The SER is estimated by a statistical Gaussian method. A typical value of 10^{-3} for BER will be used as criterion considering the possible use of forward error corrector (FEC).

After 100 km the ODSB signal starts to be very penalized by the chromatic dispersion effects. Indeed, the first frequency fading of the IM-DD channel starts to fall in the 6 GHz DMT signal band as it is shown on the top of Fig. 6. For 150 km and 200 km, the transmission is impossible in ODSB configuration. The OVSB configuration provides better immunity to chromatic dispersion effects for long distances while OSSB configuration allows best results. Considering a BER criterion at 10^{-3}, the OSSB modulation reaches 200 km with the appropriate amplification scheme. The bottom of Fig. 6 confirms that OSSB spectrum is the least distorted by the channel effects. Fig. 7 describes measured results of the channel response versus DMT subcarriers. As in simulation, the OSSB configuration presents relatively flat channel response resulting in an increase of transmission performance for 200 km.

These simulation and experimental results prove the possibility of generating wideband OSSB-OFDM signal with a monolithically integrated dual access EML by mixing FM and AM. The interest of the dual modulation, in terms of chromatic dispersion effects management, has been shown in this part at 11 Gb/s in the point-to-point amplified link context where the challenge has been to reach the maximal distance. In the next part, the dual modulation is evaluated in the PON context inducing point-to-multipoint architecture with no amplification for a maximal range of 60 km.

4. SIMULATION RESULTS FOR A POINT-TO-MULTIPOINT LINK

The system simulations including our model of D-EML show results in good agreement with experimental ones thus we performed study for higher bit rate with conventional OFDM. The target useful bit rate is 25 Gb/s for NG-PON applications. The OFDM signal is composed of 256 subcarriers (227 useful and 29 pilot) forming a 7.75 GHz signal transposed at 5 GHz. A 16-QAM modulation is used to increase further spectral efficiency. The cyclic prefix used is 12.5 %. The total bit rate is about 31.7 Gb/s allowing a 25 Gb/s useful bit rate. The simulation setup is modified in order to modulate the D-EML by the OFDM signal in a passive point-to-multipoint architecture. No optical amplification is inserted and there is no specific chromatic dispersion compensation (except OFDM equalization as in the previous part). The optical budget, *i.e.* the total attenuation between optical emitter and receiver, is controlled by the means of an optical attenuator which accounts for lumped losses due to splitting node. It is fixed at

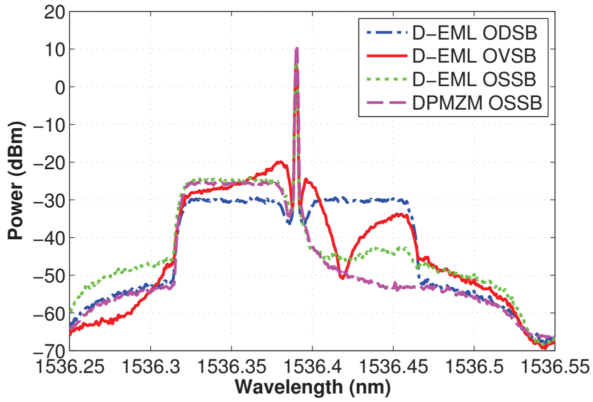

Fig. 8. Simulated optical spectra at the output of D-EML and DPMZM for comparison (resolution 1 pm).

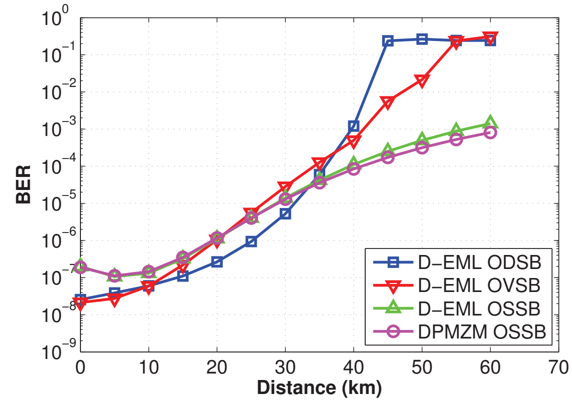

Fig. 9. BER versus distance at 25 Gb/s for the D-EML in the three configurations and for the DPMZM for comparison.

25 dB in order to be compliant with the class B of G-PON according to the ITU-T G.984 standard. The dual driver still allows the three configurations ODSB, OVSB and OSSB for the D-EML. The same link has been studied with the use of a DPMZM in OSSB configuration for comparison.

Fig. 8 presents the optical spectra at the output of the D-EML in the three configuration and for the DPMZM in OSSB configuration. The OVSB configuration exhibits a deep frequency fading inside the OFDM signal band which corresponds to the frequency used to satisfy the SSB condition in the dual driver. Contrary to OVSB, OSSB configuration of the D-EML presents a good SBPR of about 20 dB over the whole OFDM signal band. The OSSB configuration of the DPMZM performs the better SBPR which is close to 26 dB.

Fig. 9 depicts the performances versus distance for all the modulation schemes at 25 Gb/s. In ODSB and OVSB configurations the limitation is around 40 km for a BER at 10^{-3} because of the transmission impairment due to the first frequency fading of the IM-DD channel. This fading is significantly reduced in the OSSB configuration leading to an increase of maximal transmission distance around 55 km. The dual modulation of the D-EML in OSSB condition leads to performances very close to those obtained with DPMZM for which residual effect of chromatic dispersion and link loss still limit the transmission distance. Compared to the DPMZM using $LiNbO_3$, the D-EML is low-cost, more compact, and require lower control voltage making it a very interesting candidate as SSB monolithically integrated transmitter.

5. CONCLUSION

We reported on experimental results and system simulations demonstrating the enhancement of transmission distances by using a novel dual modulation technique producing a wideband OSSB-OFDM signal. The technique relies on a FM/AM combination applied on an integrated EML with dual RF access through a digital filtering providing a large-bandwidth phase-amplitude relation close to the required SSB condition. Experimentations and system simulations show an amplified point-to-point transmission at 11 Gb/s over 200 km for a BER lower than 10^{-3}. We also demonstrate by simulation a PON configuration over 55 km transmission distance for a bit rate of 25 Gb/s while keeping 25 dB optical budget.

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