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# Fabry-Perot Filtered Emission for 25 Gbit/s Single-Side Band NRZ and ODB Transmissions in C-band up to 20 km

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**Abstract** VSB-NRZ and VSB-ODB emitters based on an etalon Fabry-Perot filter is combined to a 12 GHz photodiode and electrical post-equalization to allow transmission performances at 25 Gbit/s in C-band up to 30 km.

## Data rate evolutions in the optical access network

Currently, optical access standards [1] are based on an “on/off” keying Non Return to Zero (NRZ) modulation format at emitter. Direct intensity modulation is used at transceiver side and direct detection at the receiver side. The present increase in the number of access network subscribers and their behavior in terms of daily network utilization boosts the bandwidth demand [2-3]. In order to provide the network evolution, ITU-T defined the NG-PON2, a technical solution based on Time and Wavelength Division Multiplexing (TWDM), which involves up to 8 channels working at 10 Gbit/s in downstream and/or upstream. Now, both IEEE and FSAN (Full Service Access Network) / ITU-T (International Telecommunication Union-Telecommunication) are working on the definition of NG-EPON and 25G-PON respectively, optical access technologies based on a 25 Gbit/s data bit rate. In such a context, systems based on NRZ modulation format coupled to electrical equalization techniques and signal processing have been proposed [4-5] in order to enhance the performance of the optical link. Modulation format such as Vestigial Side Band NRZ (VSB-NRZ) can be used to increase optical bandwidth efficiency and to reduce the dispersion penalty due to Chromatic Dispersion (CD) [6]. Moreover, efficient electrical bandwidth modulation formats such as optical duo-binary modulation (ODB) [7-8] are considered by the standard organisms for Next Generation PON definition.

This paper discusses about the VSB-NRZ and VSB-ODB modulation formats transmission performances at 25 Gbit/s in C-band for distances up to 20 / 30 km and the impact of post-equalization on the transmission is demonstrated.

## 25G-PON prototype description

This 25G-PON prototype (cf. Fig. 1) is based on a C-band DownStream (DS) channel (1550.57nm) and two O-band CWDM UpStream (US) channels (1271.57 nm and 1333.41 nm) operating at 10 Gbit/s. The DS emitter embeds into a CFP2 package a thematically tunable C-band DFB laser combined to a 10 GHz electrical bandwidth Mach-Zehnder Modulator (MZM) which is driven by a 25 Gbit/s NRZ stream. A fixed Fabry-Perot filter (FPF) characterized by a 100 GHz Free Spectral Range and a 25 GHz optical bandwidth is used to filter-out one band of the optical spectrum in order to produce a VSB-NRZ signal. The C-band DFB wavelength is thematically tuned in order to match it with the etalon filter central frequency. In order to compensate MZM insertion loss, an Erbium Doped Fiber Amplifier (EDFA) is used and provided a 6.2 dBm OLT output optical power after the optical multiplexer. By tuning the MZM bias point and the NRZ stream amplitude, it is possible to select either VSB-NRZ or VSB-ODB modulation format [8]. The prototype uses the electrical bandwidth of the MZM to filter the 25 Gbit/s NRZ signal into a 25 Gbit/s duo-binary signal.

At the receiver side, the optical module is based on a 12 GHz Avalanche PhotoDiode

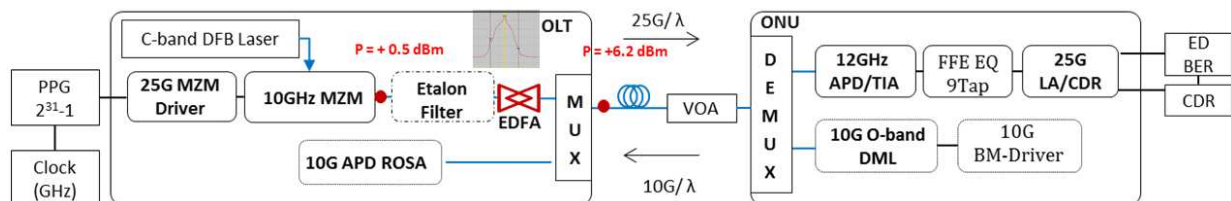


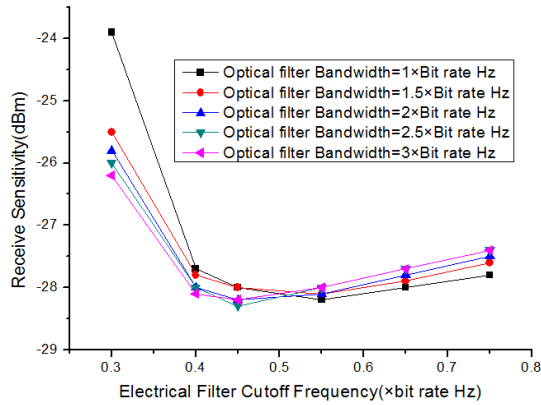
Fig. 1: 25G-PON prototype based on MZM for NRZ and ODB modulation

(APD) and directly connected to a 25 GHz electrical 9-Tap Feed Forward Equalizer (FFE) dedicated to electrical compensation of the transmission distortion which are mainly due to chromatic dispersion in C-band and electrical bandwidth limitations. The FFE is connected to a 25 GHz Linear Amplifier (LA) and a dedicated CDR working up to 25 Gbit/s.

This prototype is used to transmit  $2^{31}-1$  Pseudo Random Bit Sequence (PRBS) streams and to realize Bit Error Rate (BER) measurement. Optical transmission is performed on a link with up to 20 km of standard optical fiber and connected to a Variable Optical Attenuator (VOA).

### Some simulation results demonstrating VSB-ODB transmission performances

Fig.2 depicted received sensibility evolution according to the electrical receiver cutoff frequency and illustrates how it is possible to optimize the Fabry-Perot optical filter etalon



**Fig. 2:** Electrical and optical filter bandwidth optimization to improve receiver sensitivity in the case of ODB transmission at 25 Gbit/s (BER of  $10^{-3}$ )

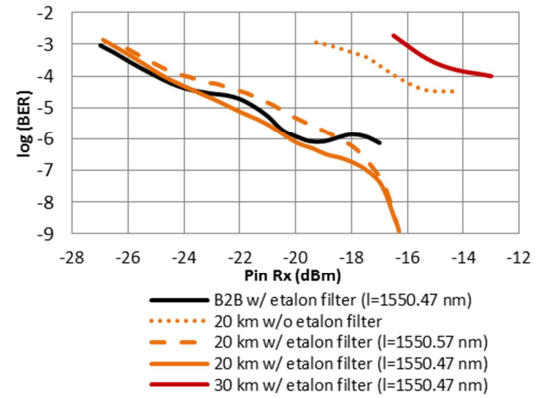
demonstrating performances improvement of VSB-ODB transmission compared to unfiltered ODB.

In the case of an ODB transmission without FPF, receiver sensitivity (BER of  $10^{-3}$ ) is obtained for -27 dBm and an electrical bandwidth of 18.75 GHz ( $0.75 \times$  Data Bit Rate). By introducing the FPF with a 25 GHz optical bandwidth, the sensitivity is improved to -27.8 dBm if combined to a 13.75 GHz electrical filter bandwidth ( $0.55 \times$  Data Bit Rate). Simulations demonstrate that it is possible to reach sensibilities like -28.3 dBm if a 62.5 / 75 GHz optical bandwidth FPF (resp. 2.5 (3)  $\times$  Data Bit Rate) is used and associated to an 11.25 GHz receiver electrical filter. Hence, it is possible to improve sensitivity up to 1.3 dB by optimizing FPF optical bandwidth and receiver electrical one as FPF allows decreasing ripples on the "0"

in the temporal space and to improve reception performances.

### 25 Gbit/s VSB-NRZ / VSB-ODB transmission performances

Fig.3 and Fig.4 summarize C-band transmissions results performances for 25 Gbit/s data bit rates in the case of VSB-NRZ and VSB-ODB. All the performances results are given for a BER of  $10^{-3}$ . Fig. 3.a depicts transmission performances with and without the etalon filter. In this case, the electrical 25 GHz 9-Tap FFE is adjusted to find the best performances for 20 km of propagation. FPF introduction improves the optical budget by 7.5 dB (VSB-NRZ modulation format). And by tuning DFB laser temperature, it is possible to slightly optimize transmission performances thanks to an alignment improvement of DFB laser wavelength and the FPF transfer function (up to 1 dB for a  $10^{-4}$  BER by moving from 1550.57 nm to 1550.47 nm). Hence, for a 20 km propagation involving VSB-NRZ modulation format, it is possible to reach

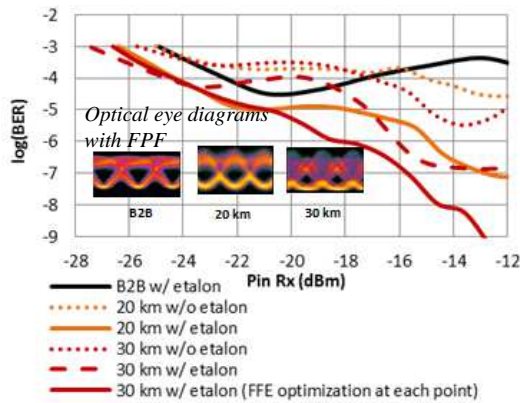


**Fig. 3:** VSB-NRZ transmission performances in C-band at 25 Gbit/s

an optical budget of 33.2 dB. For a distance of 30 km, performances were really poor as 9-Tap FFE was optimized for 20 km transmission.

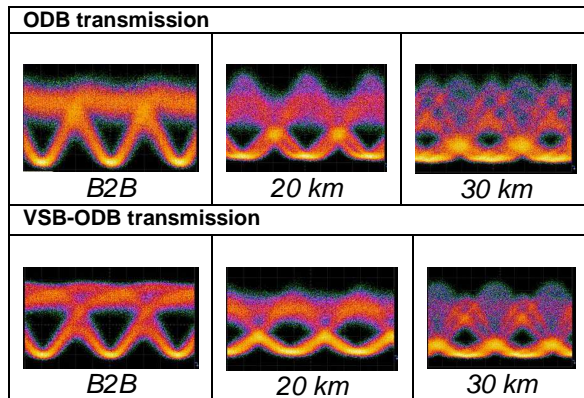
Fig. 4 illustrates transmission results in the case of a VSB-ODB modulation format for propagation distances up to 30 km. Results show that performances are very poor (about  $10^{-3}$  of BER) whatever the optical budget when no FPF is used. Measurements have been performed for a 9-Tap FFE optimized first for the BER of  $10^{-3}$  and next for each BER acquisition. Compared to ODB modulation format, VSB-ODB transmission allows lowering the BER floor of  $10^{-5}$  and FPF introduction increases by more than 1 dB the available transmission optical budget for distances of 20 / 30 km for a  $10^{-3}$  BER. Indeed, it reaches 32.7 dB for 20 km and

33.2 dB for 30 km (instead of 31.2 dB and 31.6 dB without FPF). In the case of a transmission in the C-band, VSB-ODB modulation format appears more robust to chromatic dispersion than ODB. Optimizing 9-Tap FFE for every BER measurement allows optimizing propagation performances at 30 km and to suppress the BER floor with respect to the non-optimized case.



**Fig. 4:** VSB-ODB and ODB transmission performances in C-band at 25 Gbit/s

Fig.5 depicts optical eye diagrams in the case of VSB-ODB and ODB optical transmissions in B2B and up to 30 km of optical propagation. These eye diagrams qualitatively show an eye diagram opening improvement when FPF is used and illustrating BER evolution according to modulation format and FPF use or not.



**Fig. 5:** VSB-ODB and ODB optical eye diagrams

## Conclusions

We demonstrate it is possible to use optimized modulation formats like VSB-NRZ and VSB-ODB for 25 Gbit/s transmissions in C-band. The proposed architectures allow involving 10 GHz electrical bandwidth components such MZM and a 12 GHz APD photodiode. The etalon FPF generates the VSB and by using a 25 GHz FFE component in reception, it is possible to reach

optical budgets up to 32 / 33 dB and typical distances of 20 / 30 km in the limits of a  $10^{-3}$  BER.

Next development will give the opportunity to improve the integration level of the emitter and to have BER algorithms available in reception to improve automatically 9-Tap FFE coefficients.

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