



HAL
open science

Analog FFE Coefficients Optimization Using MMSE-based LMS Algorithm in PON Context

Dylan Chevalier, Pascal Scalart, Gaël Simon, Laurent Bramerie, Michel Joindot, Jérémy Potet, Mathilde Gay, Philippe Chanclou, Monique Thual

► **To cite this version:**

Dylan Chevalier, Pascal Scalart, Gaël Simon, Laurent Bramerie, Michel Joindot, et al.. Analog FFE Coefficients Optimization Using MMSE-based LMS Algorithm in PON Context. Signal Processing in Photonic Communications (SPPCom), Jul 2024, Quebec, Canada. hal-04921880

HAL Id: hal-04921880

<https://hal.science/hal-04921880v1>

Submitted on 30 Jan 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Analog FFE Coefficients Optimization Using MMSE-based LMS Algorithm in PON Context

Dylan Chevalier^(1,2), Pascal Scalart⁽³⁾, Gaël Simon⁽¹⁾, Laurent Bramerie⁽²⁾,
 Michel Joindot⁽²⁾, Jérémy Potet⁽¹⁾, Mathilde Gay⁽²⁾, Philippe Chanclou⁽¹⁾,
 Monique Thual⁽²⁾

(1) Orange, 2 avenue Pierre Marzin, 22307 Lannion, Brittany, France,

(2) Univ Rennes, CNRS, Institut FOTON - UMR 6082, F-22305 Lannion, Brittany, France,

(3) Univ Rennes, IRISA - UMR 6074, F-22305 Lannion, Brittany, France,

dylan.chevalier@orange.com

Abstract: A novel approach is proposed for Analog Signal Processing (ASP) in enhanced 50G-PON using analog FFE filters based on MMSE technique. Performance are validated through experimental transmission of electrical NRZ signals. © 2024 The Author(s)

1. Introduction

The 50 Gigabit capable Passive Optical Network (50G-PON) was recently released by the International Telecommunication Union (ITU-T). It proposes a Downstream (DS) rate of 50 Gbit/s in Non-Return-to-Zero (NRZ) [1]. To compensate the bandwidth limitations of low-cost components, such as cheap 25G class receivers, several studies demonstrated the interest of using Digital Signal Processing (DSP) in Passive Optical Network (PON) by the introduction of Feed-Forward Equalizer (FFE) [2, 3]. However, analog FFE (FFE-ASP) solutions may be preferred to DSP [4] as they require fewer energy resources than DSP solutions. Unfortunately, it is still challenging to find the optimum coefficients of the equalizer, as 1) the number of combinations is extremely high and 2) analog processing requires to take into account the imperfection of the device, i.e. the limited bandwidths of each FFE tap as well as the non-linear response of the FFE-ASP. In this paper, we propose a new method to optimize the parameters settings of an FFE-ASP filter based on an optimal Minimum Mean Square Error (MMSE) approach using the Least Mean Squares (LMS) algorithm. The taps optimization of FFE-ASP is generally carried out using Zero Forcing (ZF) approach [5]; however it happened not to converge to ideal set of parameters in our previous experiments [4]. This is the reason why we propose an implicit trade-off approach between the amplification of channel noise and the suppression of InterSymbol Interference (ISI).

2. Experimental Setup

The experimental setup is presented in Fig. 1.a. An electrical real-time NRZ signal is generated with a Pulse Pattern Generator (PPG) with a bitrate of 50 Gbit/s. To emulate the low-pass filtering effect of the low-cost components within the transmitting chain, a Bessel Radio Frequency (RF) filter with a cutoff frequency (F_c) of 13 GHz is inserted between Transmitter (Tx) and receiver (Rx). At Rx side, the equalization is realized with a 6-taps FFE-ASP (see frequency responses on Fig. 1.b) and a delay between each tap of about 7.5 ps. However, each equalizer tap can be adjusted through 255 different positions, leading to a huge combination discrete problem for the entire equalizer. The search for the FFE optimal taps is carried out by first capturing the received signal with a Real-Time Oscilloscope (RTO) at a sampling rate of 100 GSa/s and a bandwidth of 33 GHz, and then searching for the optimal FFE parameters taps using off-line processing. Bit Error Rate (BER) is measured with an Error Detector (ED) and eye diagrams with a Digital Communication Analyzer (DCA). The optimal tap coefficients are the results of a two-step procedure: firstly, the impulse responses $h_{jk}[n]$ (each tap being numbered with parameter k , and j standing for its setting from -127 to 127) are computed from the measured S-parameters (frequency responses) for each possible coefficient setting among 255 possibilities (the other five coefficients set to zero). Compared to a FFE-DSP, FFE-ASP energy does not vary linearly with the index taps. The FFE-ASP is then modeled in Eq. 1 as a linear combination of 6 normalized impulse responses $h_{jk, norm}[n]$ with coefficients $c_{jk}[n]$ (with $c_{jk}[n] = \|h_{jk}[n]\|$).

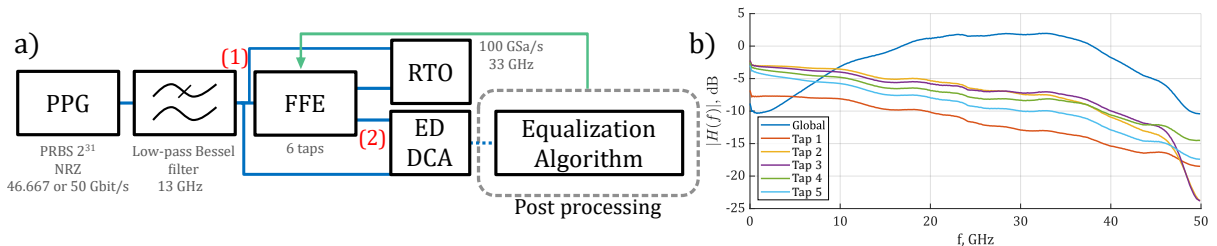


Fig. 1: a) Experimental setup & b) Global frequency response of the FFE and of each tap (tap 1: 0; 127; 0; 0; 0; 0)

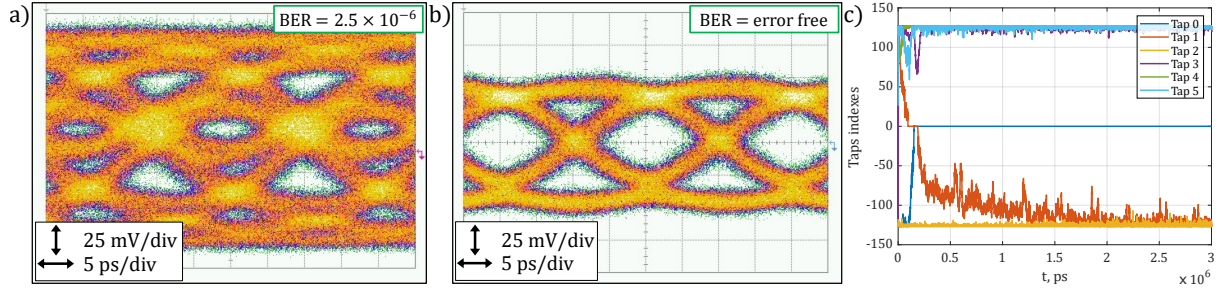


Fig. 2: **a)** Eye diagrams at the output of the Bessel filter ((1) on Fig. 1), **b)** The output of the FFE ((2) on Fig. 1) & **c)** Taps indexes evolution through time (ps).

$$\forall j \in \llbracket -127, 127 \rrbracket, \quad h_{FFE}[n] = \sum_{k=0}^5 c_{jk} \times h_{jk, norm}[n] \quad \text{with} \quad h_{jk, norm}[n] = \frac{h_{jk}[n]}{\|h_{jk}[n]\|} \quad (1)$$

The introduction of the coefficients c_{jk} deeply modifies the problem to be solved, since it can now be expressed as a classical Mean Squared Error (MSE) minimization problem (see Eq. 2). Consequently, assuming in a second step that the impulse responses $h_{jk, norm}[n]$ are quasi-constant for local variations in the index j (at least they retain their unity norm properties), the optimization problem can be expressed as the search for the optimal values of $c_{jk}[n]$ by selecting its optimal j 's setting for each tap number $k \in \{0, 1, \dots, 5\}$. This can be realized using an iterative procedure such as the Normalized LMS (NLMS) algorithm [6] that provides the updated value of the coefficients $c_{jk}[n]$ (see Eq. 3, $x[n]$: sample at the input of the FFE-ASP) in order to minimize at convergence the MSE measured between the input ($z[n]$) and the output ($\hat{a}[n]$) of the decision circuit.

$$J = \min_{j \in \llbracket -127, 127 \rrbracket} \mathbb{E}(\hat{a}[n] - h_{FFE}[n] * x[n])^2 \quad (2)$$

$$\forall k \in \llbracket 0, 5 \rrbracket, \quad c_{jk}[n+1] = c_{jk}[n] + \mu e[n] z[n] \quad \text{with} \quad z[n] = h_{FFE}[n] * x[n] \quad (3)$$

3. Results

Eye diagrams before and after the FFE-ASP are represented respectively on Fig. 2.a and Fig. 2.b. When a 50 Gbit/s signal passes through the 13 GHz filter, we can see the effect of ISI (Fig. 2.a). Before equalization, we obtain a BER at 2.5×10^{-6} . After equalization, the ISI was reduced, the eyes opened and finally, an *error free* is obtained. It is important to emphasize that the target BER in PON is 10^{-2} (this limit corresponds to the 50G-PON standard forward error correction threshold). On Fig. 1.b, the blue curve represents the global frequency response of the FFE-ASP which does boost high frequencies. In Fig. 2.c, the time evolution of the six indexes of the FFE-ASP filter coefficients is represented. We can see that the initial time convergence of the coefficients is relatively fast since the adaptive algorithm requires no more than $1 \mu s$ to converge towards the optimal coefficients solution. At convergence, the variance of the estimated indexes is relatively low indicating that a stable local minimum has been found by the NLMS algorithm. Moreover, we can notice that five out of the six coefficients indexes exhibit large asymptotic values, since they are close to the extreme values ± 127 . As a consequence, the corresponding FFE-ASP filter solution will provide a high gain since high coefficient indexes are related to high amplitudes of the FFE-ASP taps.

4. Conclusion

In this paper, we proposed a new way to determine the optimal parameters to perform analog processing in the 50G-PON with an FFE-ASP based on a MMSE technique. This solution was experimentally validated with an electrical NRZ signal transmission at 50 Gbit/s. This allowed us to improve the quality of our eye diagram and reduce the BER in PON.

Acknowledgments

This work was led in OCTAPUS HORIZON-CL4-2021-DIGITAL-EMERGING-0106 project.

References

- [1] "ITU-T, G.9804.3: 50-Gigabit-capable passive optical networks: PMD layer specification," Feb. 2023.
- [2] G. Simon et al., "50Gb/s TDM PON Digital Signal Processing Challenges," in *ECOC*, 2020.
- [3] G. Simon et al., "Equalizer convergence for various transmission channels and multi-rate ...," in *OFC*, 2020.
- [4] J. Potet et al., "Uncooled high speed ge/si avalanche photodiode for 50 gbit/s-PON with 60 km ...," in *OFC*, 2023.
- [5] O. Eshet et al., "An adaptive 4-tap analog FIR equalizer for 10-gb/s over backplane serial ...," in *ESSCIRC*, 2008.
- [6] B. Widrow, "Adaptive filters," in *Aspects of Network and System Theory*, pp. 563–586, 1971.