# Nonlinearity Compensation and Equalization in Access Networks

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**Abstract**

**In this paper we give an overview over the nonlinear impairments arising in passive optical networks (PON) and show different approaches to compensate for them before and after the transmission.**

## I. Introduction

Due to constantly increasing demand of communication bandwidth future access technologies will most likely be optical. As in access networks, cost is an important factor, low-cost optical components like direct modulated lasers (DML) and direct detection (DD) with a single photo diode (PD) might be the choice. One major drawback of these techniques is their nonlinear behavior, which can decrease the data rate and the reach, compared to systems with external optical modulation and coherent detection. However, the use of electronic compensation of the optical impairments can allow an increase of the data rate and the reach of the optical network. In this paper we give an overview about the nonlinear effects in access networks and methods for their compensation.

## II. Nonlinearities in Optical Access Networks

### A. Direct Laser Modulation

The cheapest way to modulate an optical carrier is to turn laser on and off according to the data to be transmitted. The emitted optical intensity is proportional to the photon density in the active region of the laser. The photon density $S(t)$ depends on the carrier density $N(t)$ and the modulation current $I(t)$. The relationship can be expressed with a set of rate equations [1] resulting in nonlinear intensity modulation and also in a frequency modulation which leads to spectral broadening. The time deviation of the optical phase is called chirp, which can be divided into adiabatic chirp (proportional to optical intensity) and transient chirp (proportional to logarithmic time deviation of $P_{opt}(t)$). For back-to-back transmissions laser chirp can be neglected but the presence of optical filters and dispersion might result into FM to AM conversion and thus degradation.

### B. Fiber Nonlinearities

The fiber nonlinearities which result in self and cross phase modulation (SPM and XPM) can typically be neglected in access links because of the limited distances.

### C. Direct Detection

Finally the direct detection at the receiver can be regarded as another nonlinear impairment, because the PD current is proportional to the squared optical field and thus all linear impairments in the optical link like dispersion translate into nonlinear distortions.

## III. Pre-Compensation techniques

Compensation of these impairments can be done by adding artificial nonlinearities so, that in the end these effects cancel out. These additional nonlinear functions can be applied to the signal before or after the transmission. In PON it might be preferable to place the compensation into the OLT because here costs can be shared across multiple ONUs. In the downlink this means a pre-compensation, in uplink a post-compensation.

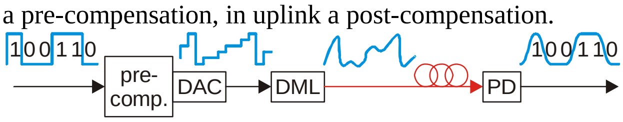


Fig.1. Schematic link with pre-compensation

### A. Inverse Calculation of Rate-Equations

With detailed knowledge of the laser parameters the modulation impairments can be compensated for by an inverse calculation of the rate equations [2]. For a desired intensity pattern the required modulation signal is retrieved. Because the complexity is too large to be done in realtime, the required laser current for all data sequences of limited length could be pre-calculated and stored into a look-up-table (LUT). The data sequence of limited length (5 bit in Fig. 2) is used for addressing a LUT and the corresponding current is converted using a digital to analog-converter.

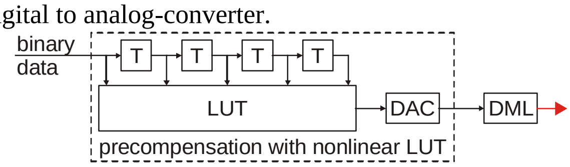


Fig.2. Efficient implementation of pre-compensation of the laser current

### B. Feedback Optimization

Although the above method is straight forward, it requires detailed knowledge of the laser parameters and only compensates for the modulation but not for other system impairments. Another method is to optimize the LUT for overall system performance using feedback information [3]. Here a quality parameter of the received signal is used to select the LUT with best performance.

Thus all impairments are considered, but the setup is more complex. While the first approach is best for back-to-back, the second approach is best around the target distance of the LUT-optimization.

## IV. Post-Compensation techniques

With post-compensation the transmitter can be very simple. Here the binary data is directly used to drive the DML. At high data rate and long distances the optical eye may be closed at the receiver, thus simple decision is not possible anymore. However by applying nonlinear equalization (EQ) the information can be recovered. EQ which are implemented with digital signal processing typically require an analog to digital converter (ADC). The LUT approach may not be used at the receiver side because ADC wordlength and channel memory length result in prohibitively large LUT size.

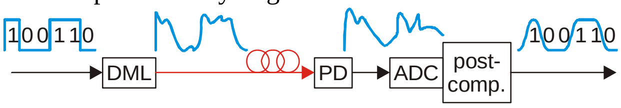


Fig.3. Schematic link with post-compensation

### A. Nonlinear Volterra Equalizer

Here nonlinear Volterra equalization is a possible approach which is an extension of a linear feed forward equalizer (FFE) and decision feedback equalizer (DFE) of higher order combinations of the delayed signal [4]. Fig 4 shows a possible implementation of a nonlinear FFE with one delay element and a linear DFE with two delay elements.

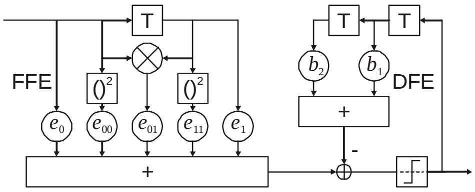


Fig.4. Example of nonlinear Volterra equalizer with nonlinear feed forward and linear decision feedback part

### B. Maximum Likelihood Sequence Estimation

Another method for the compensation is maximum likelihood sequence estimation (MLSE) which is efficiently implemented with the Viterbi-Algorithm. Here the most likely transmitted sequence is derived using previous decisions and the knowledge of channel response for each sequence.

## V. Results

We compared the performance of the described compensation schemes using numerical simulations. The transmitter optical field is derived from the modulation current with the DML rate equations, thus modulation nonlinearity and chirp are included. The optical link consists of 100km SSMF and a 50 GHz optical filter to model the AWG in WDM-PON. At the receiver the optical intensity is detected with a PD. Thermal noise is added with a density of $20\text{pA}/\sqrt{\text{Hz}}$. Since no optical amplification is applied, this is the only noise source in our simulations. Without compensation, error free communication is not possible because of the linear and nonlinear impairments. With pre-compensation with a LUT that was optimized for the given link using feedback information the performance is significantly improved.

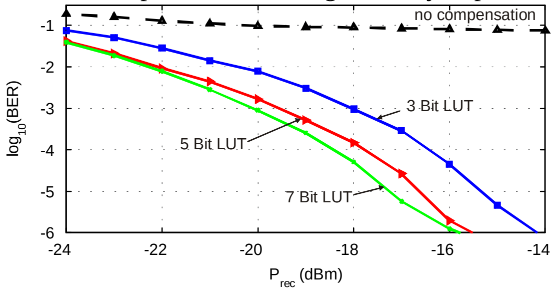


Fig.5. BER vs. received optical power with pre-compensation

Fig. 6 shows the improvement of the link performance, when compensation is done at the receiver side using nonlinear FFE-DFE combinations and MLSE with different memory lengths.

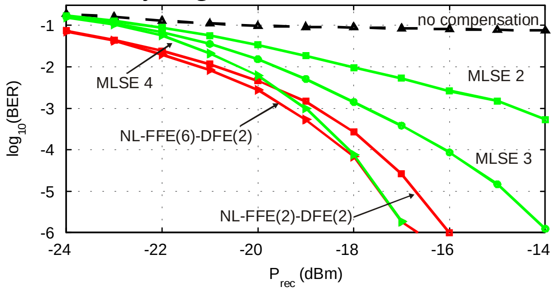


Fig.6 BER vs. received optical power with post-compensation

We conclude that both, pre- and post-compensation are able to reduce transmission impairments to a considerable extend. Both methods require some kind of channel estimation in order to become adaptive. Thus pre-compensation seems to be less beneficial as a feedback channel is required for adaptive operation.

## VI. Conclusions

In this work we give an overview over the main sources for nonlinear distortions in optical access networks. We list some approaches for their compensation and show the improvement with numerical simulation. Because electrical solutions are regarded to be more cost efficient compared to optical solutions, these techniques might be the choice for increasing the data rate and the reach of optical networks.

## References


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