# A new LightGBM-based Equalizer enabled high-capacity PAM-4 and NRZ transmission in the 10-G class system


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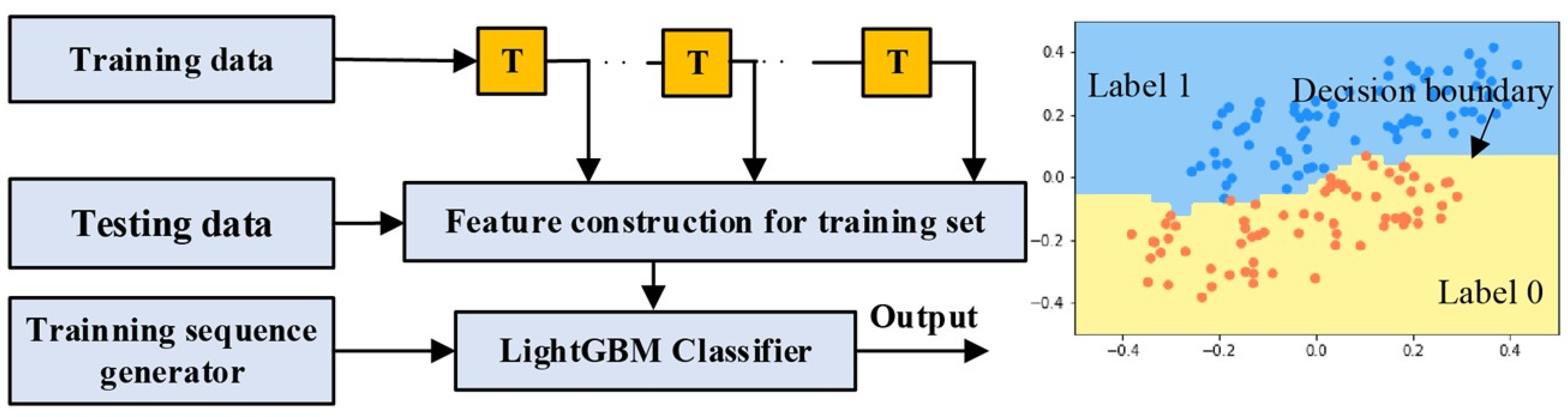
## Abstract

We design a LightGBM-based equalization scheme to achieve the target of high capacity and low cost in the bandwidth-limited IM/DD system. It is then applied to a system based on 25 Gb/s NRZ and 50 Gb/s PAM-4 in 10 GHz optical devices to manifest its feasibility. Results indicate that, compared to the 37-taps DFE, our method obtains 2.5 dB performance improvement in both 20km standard single-mode fiber (SSMF) and KP4-FEC threshold (BER=2.2E-4) back-to-back (B2B) transmission in the case of 25 Gb/s NRZ. For the 50 Gb/s PAM-4 proposed scheme can improve the sensitivity by 2 dB under the HD-FEC limit (BER=3.8E-3) compared to the common DFE with 37 taps.


## Principle and Method




The feature vector of the training sequence is constructed by the tap delayer, which can be described as,

$$\mathbf{X}_i = \left[x_{i-n}(d), x_{i-n+1}(d), \ldots x_i(d) \ldots, x_{i+n-1}(d), x_{i+n}(d)\right]$$

Here, LightGBM is used to train a tree-based model for equalization. As a framework, the LightGBM can implements the GBDT algorithm efficiently for classification. On this basis, a series of weak classifiers (CART) will be generated by learning the residuals (The negative gradient of the loss function) of the previous weak classifier to obtain the optimal equilibrium. Throughout these processes, the trained leaner can be finally achieved, which can be given as,

$$f(x) = f_0(x) + \sum_{t=1}^{T} \sum_{j=1}^{J} c_{tj} I\left(x \in R_{tj}\right)$$

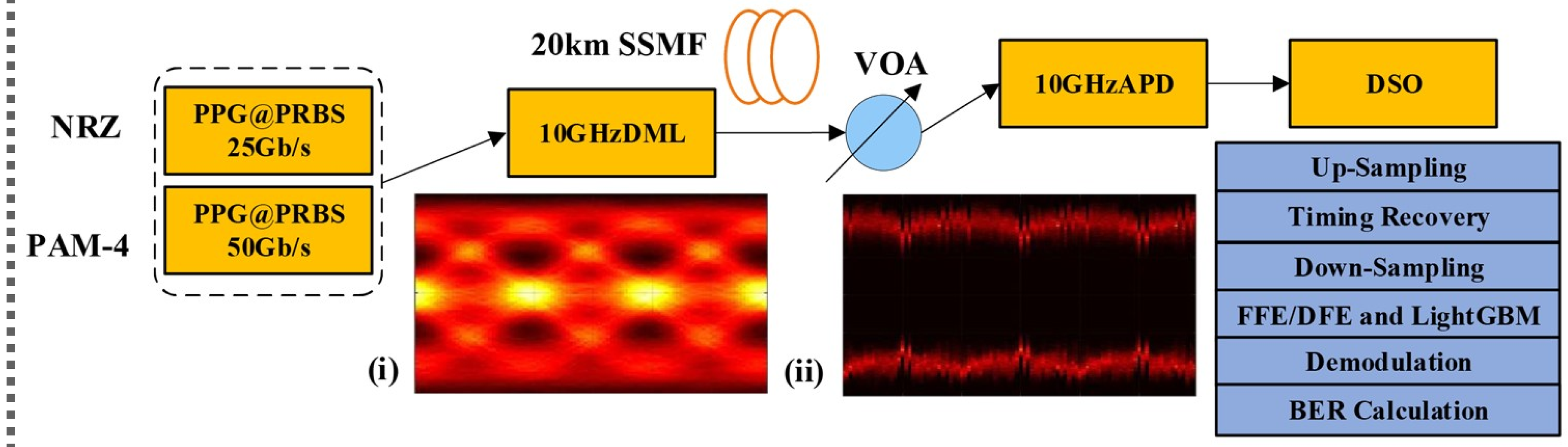
where $f_0(x)$ is the initialized base learner, which can be understood as a constant. T is the number of week learners, and J is the index of the leaf nodes in each weak learner. $c_{tj}$ represents the value of leaf node j in the t-th tree, I is the index function, and the expression I $\{x \in R_{tj}\}$ indicates that if sample x is in the leaf node $R_{tj}$, then return 1 otherwise return 0.

In the equalization stage, valid data is input to the trained tree model to obtain the corresponding predicted value, and then this value is used as the input of the sigmoid function, which can be described as,

$$\sigma(x) = \frac{1}{1 + e^{-x}}$$

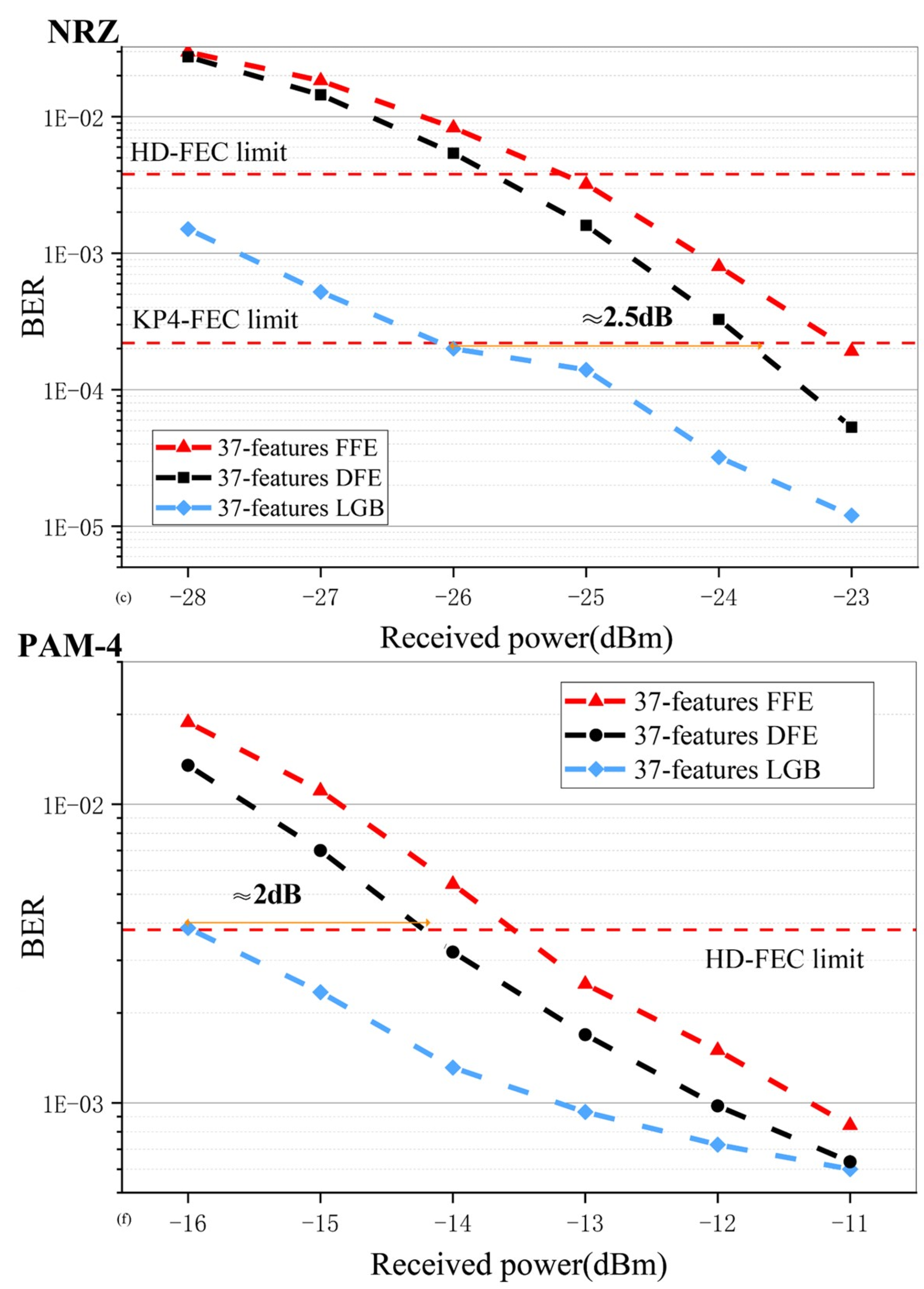
This function maps the calculated value to the interval of (0,1) to get the probability that the sample label is 1. Then the output is used to judge with the threshold of 0.5, and the judgment result is the final equalization result. At the same time, the visualization of the equalization effect of the LightGBM equalizer is also shown in the figure. The decision boundary obtained from the training sample classifies the sample points very well, which also confirms the equalization effect of the scheme.

## Experiment setup




This figure gives the corresponding experiment configuration of this paper, which is utilized to manifest our scheme. The eye diagram of NRZ before and after our equalization is presented in (i) and (ii), respectively. Obviously, for our scheme, the eye becomes large which can achieve a good BER performance.

## Conclusion




Here, the parameter of the presented each equalizer have been configurated the optimal states of itself (DFE / FFE is the optimal value within 37 taps and its optimal training lengths, LightGBM is 37 taps and 6000/10000 training lengths respectively for NRZ and PAM-4).

Comparing to the 37-taps DFE and FFE, LightGBM obtains 2.5dB sensitivity improvement @ BER = 2.2E-4 (KP4 FEC limit) for 25Gb/s NRZ and 2dB @ BER = 3.8E-3 (HD-FEC limit) for 50Gb/s PAM-4.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