BTP-1
Progress Evaluation

Title of Project:

Non-Linearity Mitigation in VLC Using Machine Learning

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Outline of Presentation

- Introduction to VLC (Visible Light Communication) and its advantages
- Basic Architecture of VLC
- LED and its Characteristics in VLC
- Why OFDM is Used in VLC
- QPSK/QAM Signal Transmission using LED and OFDM
- Disadvantages of LEDs as Transmitters
- Effect of Limited Modulation Bandwidth on the Received Signal
- Deep Learning Model for Non-Linearity Mitigation
- Results and Discussion
- Conclusion and Future Work

Visible Light Communication Introduction and Application

- The visible light communication (VLC) refers to communication technology which utilises the visible light source as signal transmitter.
- VLC is a subset of optical wireless communications technologies. Visible light is only a small portion of the electromagnetic spectrum. The technology uses LEDs.

Advantages:

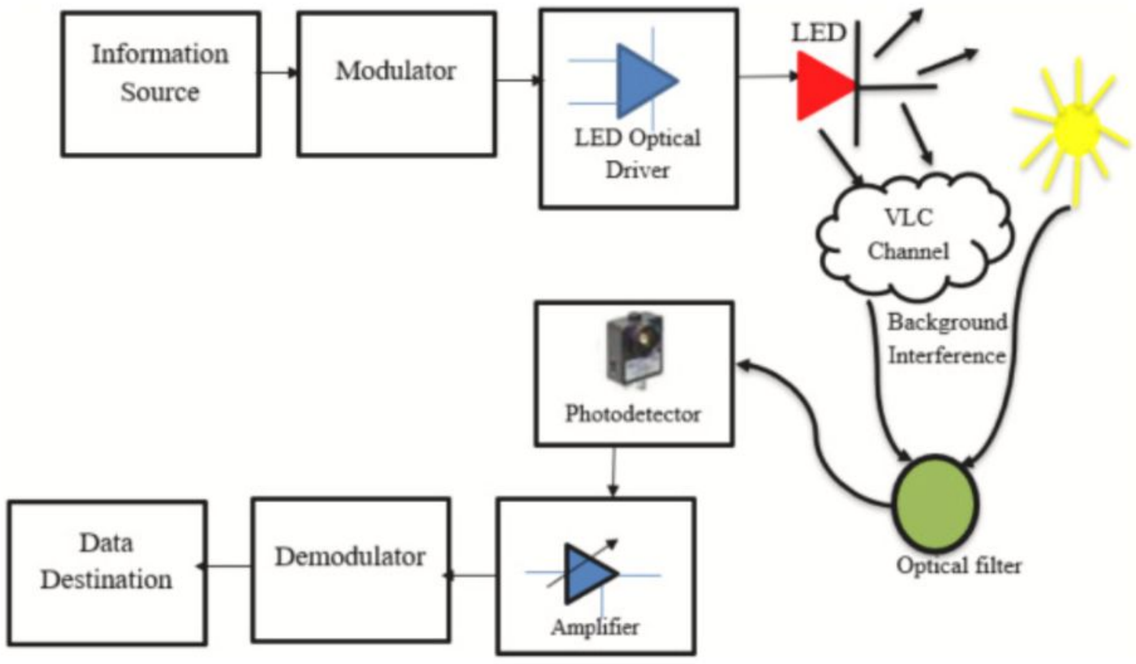
- Increased Security
- Higher Data rates
- Lower Interference(Not affected due to EM radiations)
- Indoor positioning
- Internet access

Basic Architecture of VLC:

- Light source
  A light source, such as an LED or laser diode, emits light at a visible wavelength.

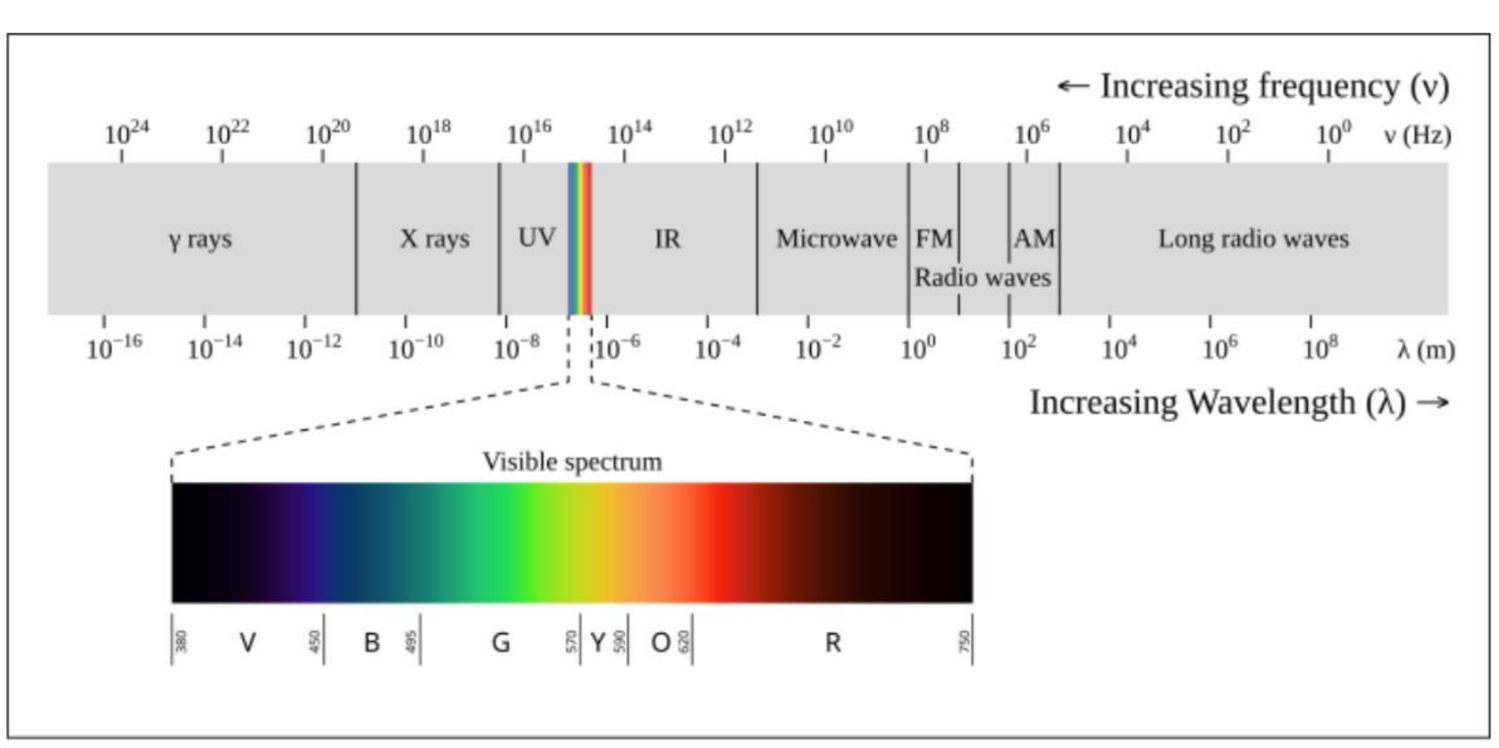
- Modulation
  The intensity of the light is modulated to transmit data.

- Reception
  A photodiode device receives the signal and converts it into a readable format.



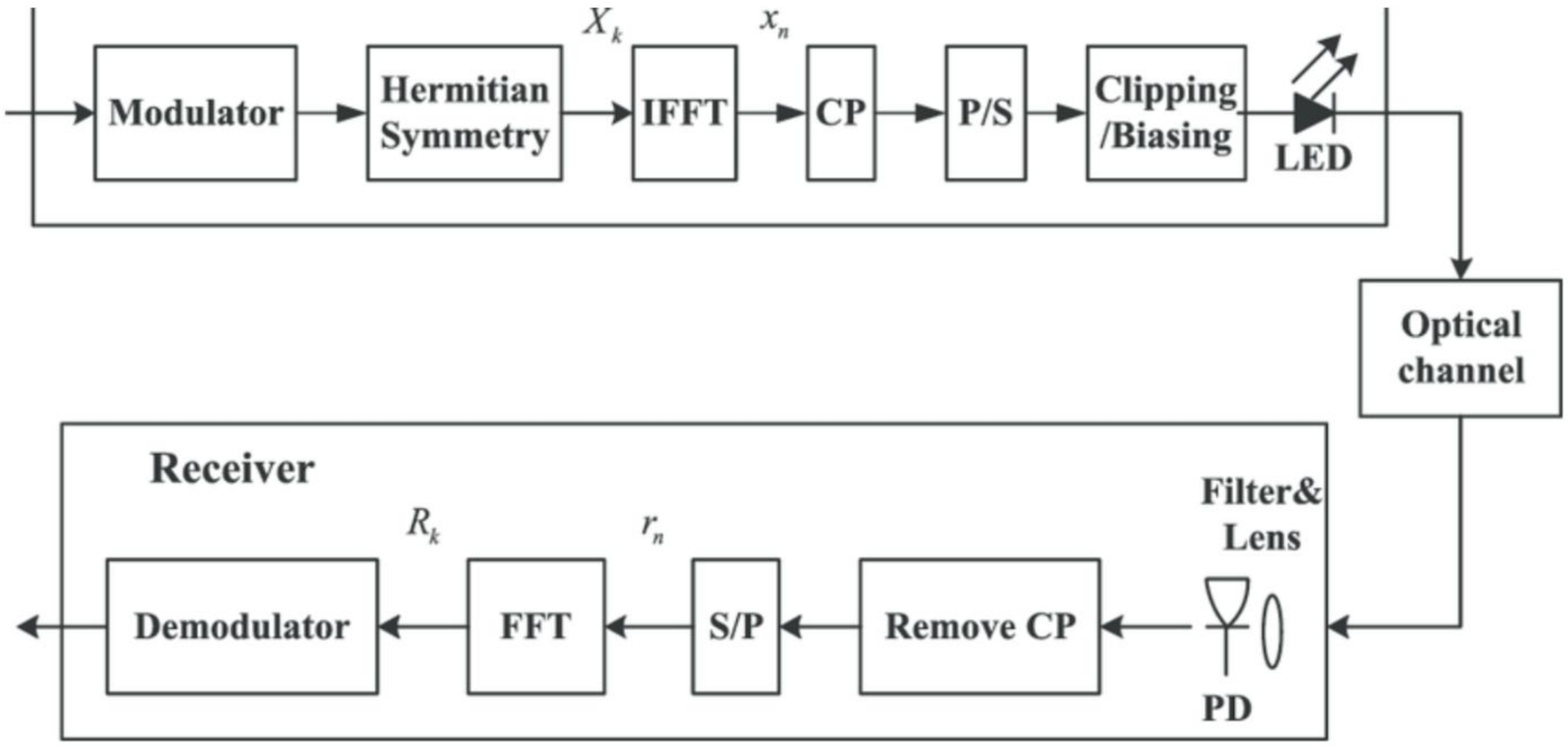
LED and its characteristics:

- Fast switching capability
- Offering dual function of Illumination and communication
- Non-liner I-V characteristics
- Beam divergence
- Bandwidth Limitation



Orthogonal frequency division multiplexing (OFDM) is used in visible light communication (VLC) systems for a number of reasons.

- **Bandwidth efficiency: OFDM can efficiently use the bandwidth of LEDs.**
- **Reduced inter-symbol interference: OFDM can reduce the effects of inter-symbol interference (ISI).**



Research Gap and Motivation :

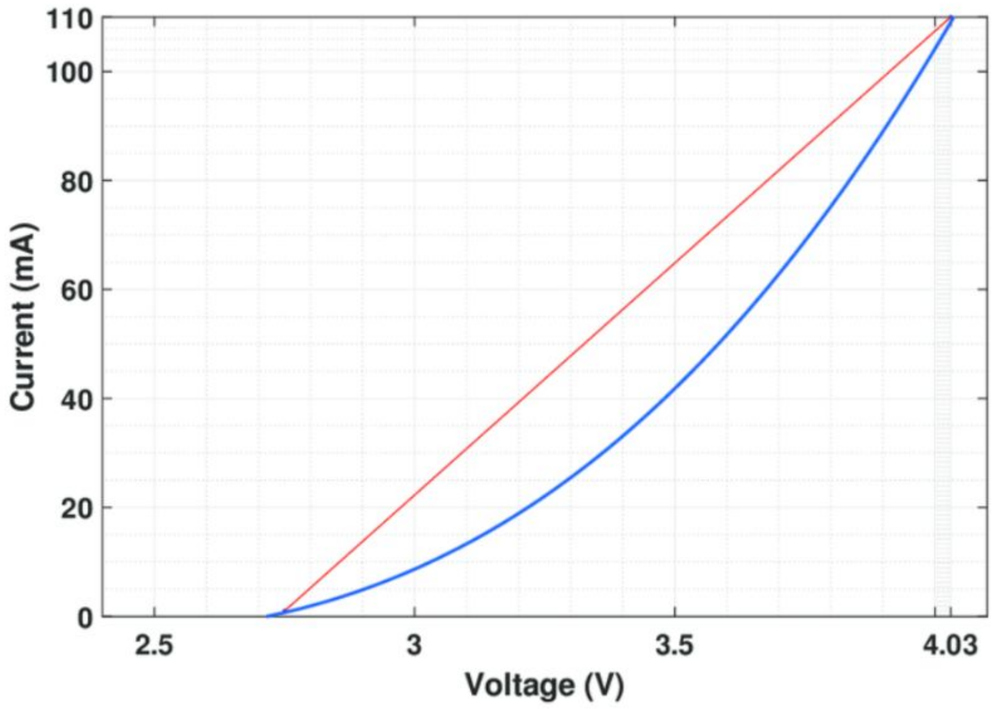
Conventional Limitations: Traditional QAM demodulation methods struggle in environments with noise and non-linearities, especially when a low-pass filter (LPF) is used. The challenge is accurately recovering data when these distortions are significant.

Comparison with Traditional Methods: The project provides a direct comparison between a machine learning-based approach and conventional methods that is QAM demodulation using matlab.

The ultimate goal was to contribute to advancements in communication technology by demonstrating that machine learning can be a viable alternative to traditional methods, offering improved performance in challenging conditions.

Disadvantages of LED as Transmitter

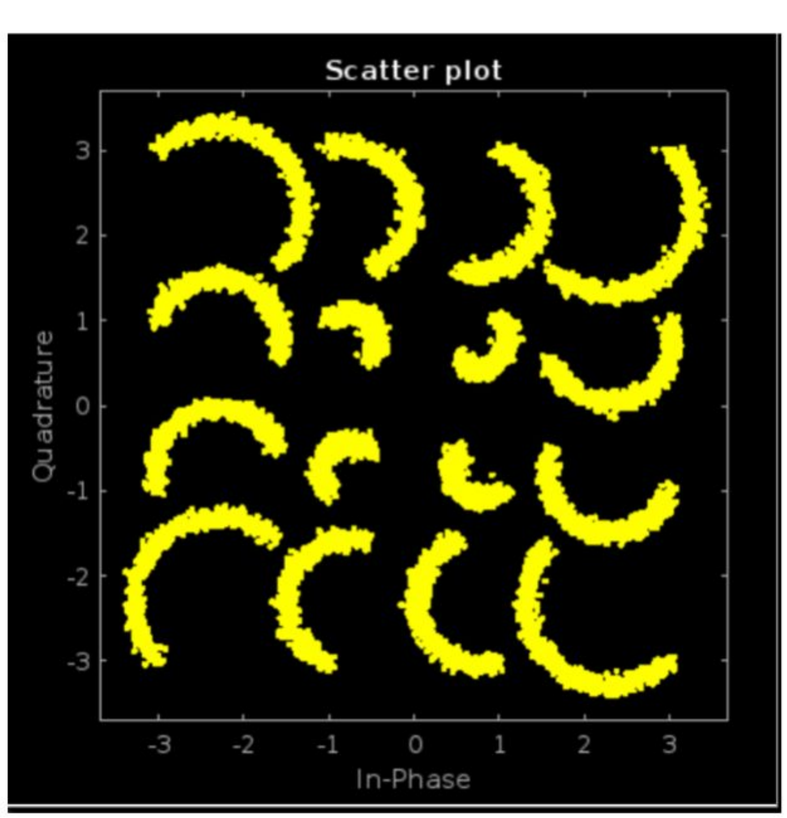
- LEDs have a limited bandwidth for modulating signals.
- LEDs exhibit a nonlinear current-voltage (I-V) curve.
- LEDs have low optical power output.
- LEDs emit light in a wide-angle (divergent) beam rather than a focused beam like lasers.



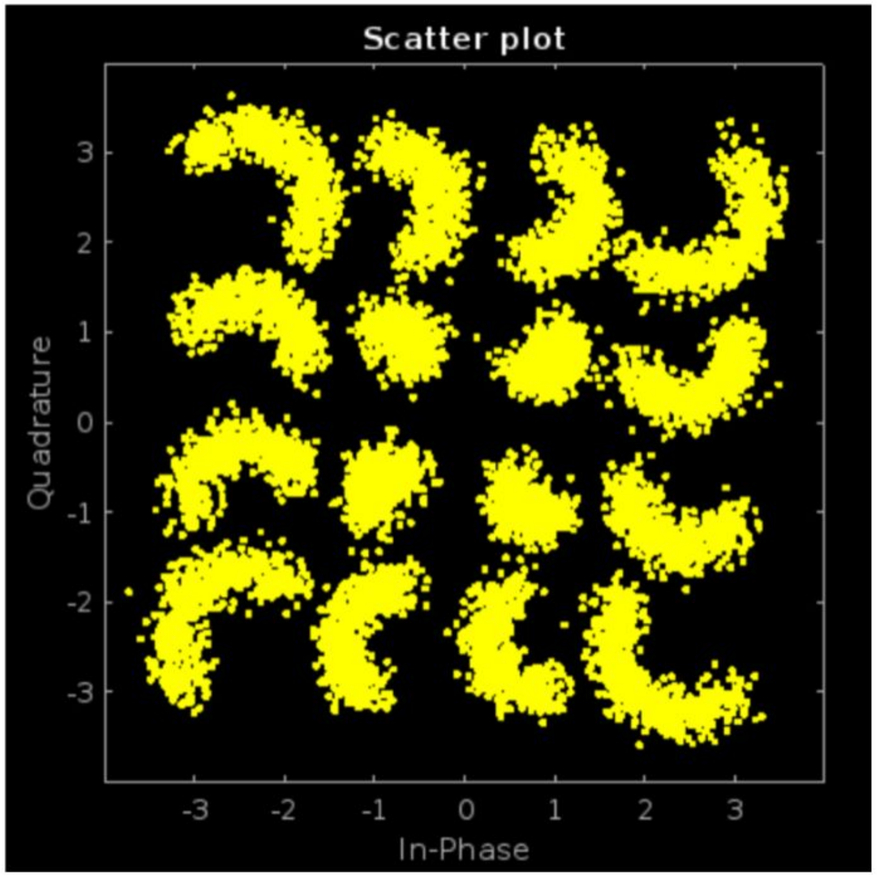
The **limited modulation bandwidth** of LEDs in Visible Light Communication (VLC) systems introduces several critical issues that impact the signal quality.

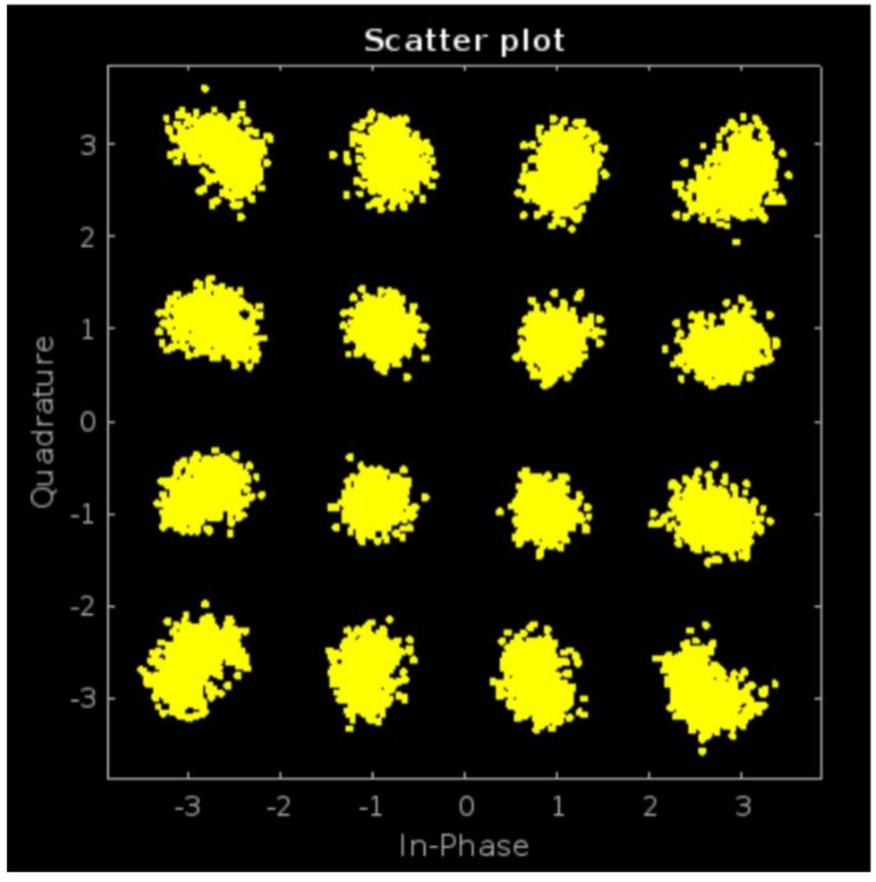
- Signal Distortion:The limited bandwidth of LEDs, typically in the range of a few MHz, acts as a low-pass filter for high-frequency components in modulated signals.

- High-frequency components of the modulated signal are severely attenuated or completely filtered out. This attenuation distorts the signal, as key high-frequency information is lost during transmission.



- For example constellation of received data at 6MHz Bandwidth and SNR 52

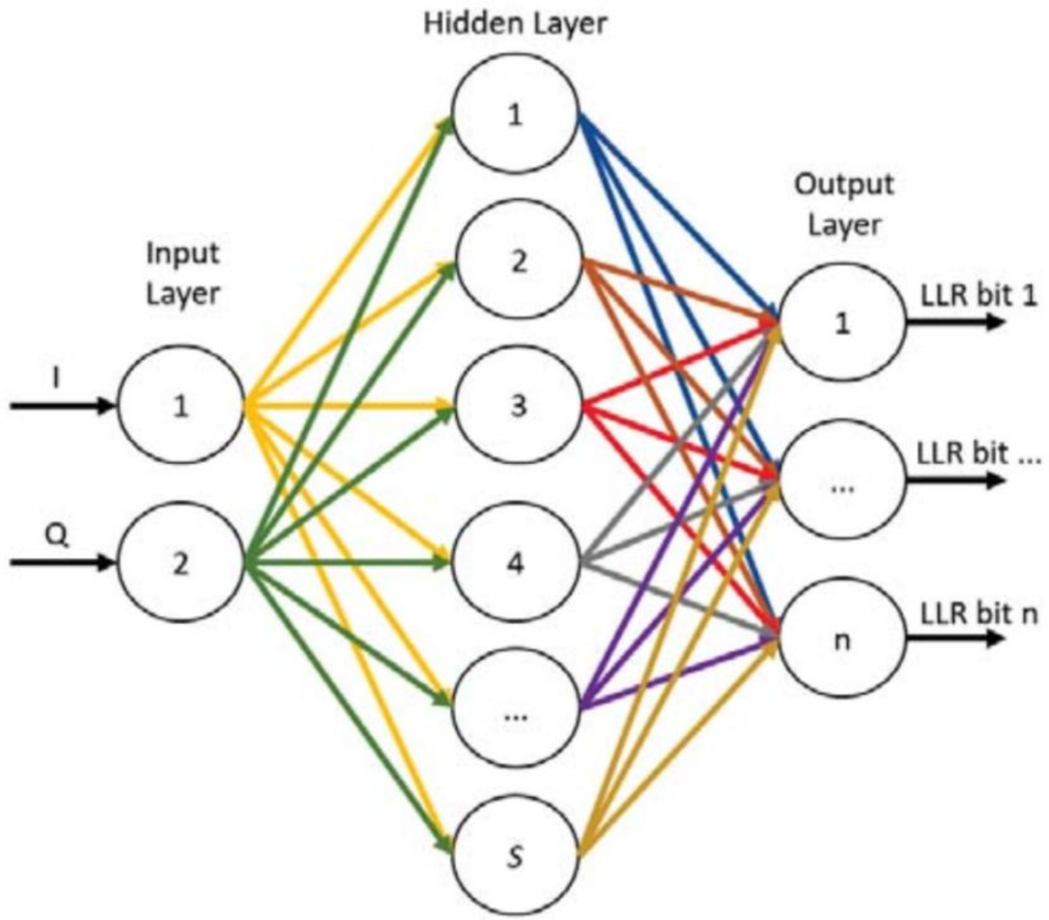




- For example constellation of received data at 7MHz Bandwidth and SNR 44
- constellation of received data at 11MHz Bandwidth and SNR 44

- We can observe that non-linearity is more in case of limited bandwidth that is 7MHz compared to that of 11MHz.

- Neural networks and other advanced algorithms are increasingly being used to model and mitigate the nonlinear distortions caused by bandwidth limitations and the LED's inherent nonlinearity.
- Artificial Neural Network (ANN) architecture can be used for mitigating the non-linearity induced by limited LED bandwidth in Visible Light Communication (VLC) systems.



- Neural network representation.

Artificial Neural Network (ANN) Architecture

The Artificial Neural Network (ANN) used here is a Multi-Layer Perceptron (MLP), designed to model the relationship between a nonlinear received signal and desired bits. The MLP is trained at optimal bandwidth and Signal-to-Noise Ratio (SNR) to ensure good performance across various bandwidths and SNRs.We train the model with distorted received signal to give output of actual bits.

Network Structure:

Input Layer:

- Takes in received serial data (split into real and imaginary parts of complex numbers), making it a 2-input model.
- Normalization is applied as a preprocessing step to generalize the model, allowing it to be tested on signals with any power level without retraining.

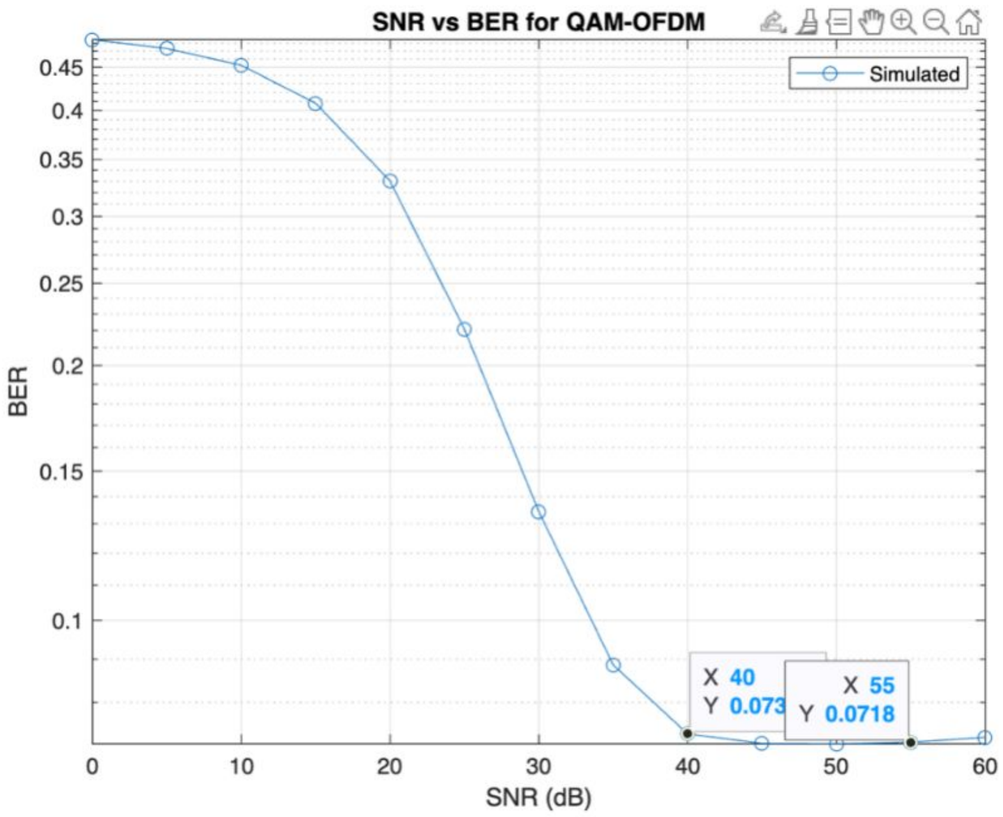
Hidden Layers:

- Contains two hidden layers with 64 and 16 neurons, respectively.
- It is fully connected dense layer.

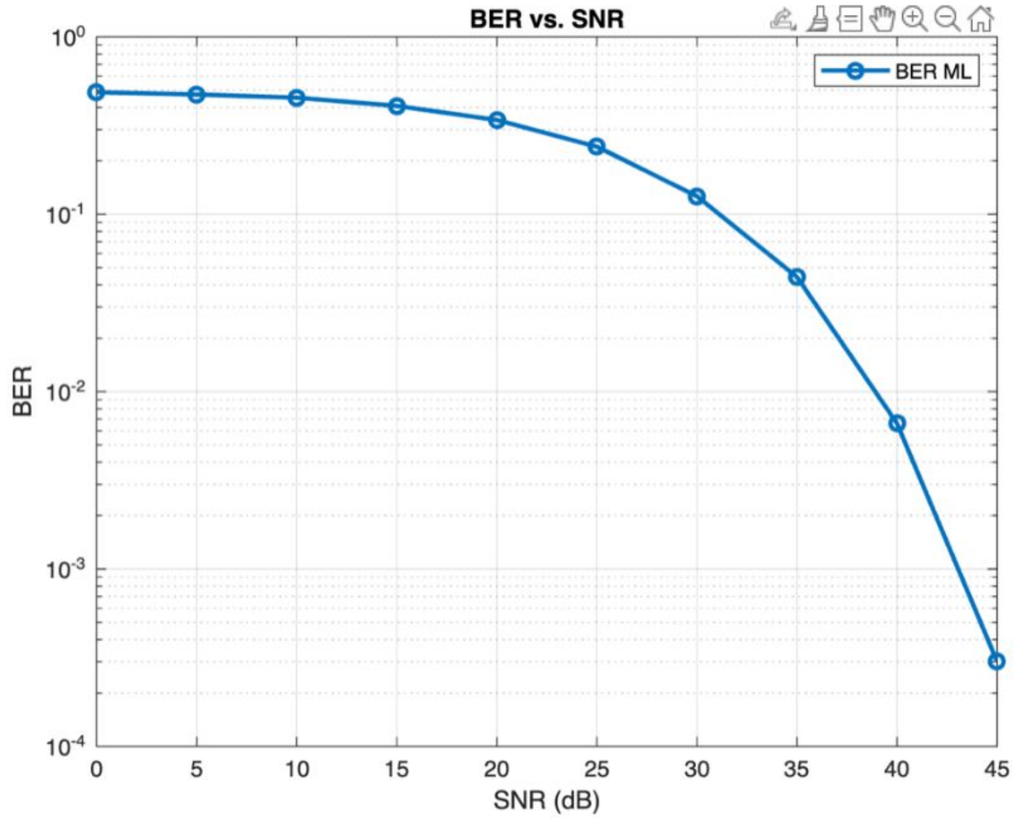
Output Layer:

- Outputs the predicted bits,removing the effect of non-linearity of the received signal.
- Bit error ratio (BER) is calculated by comparing predicted bits to actual bits, assessing the model's accuracy.

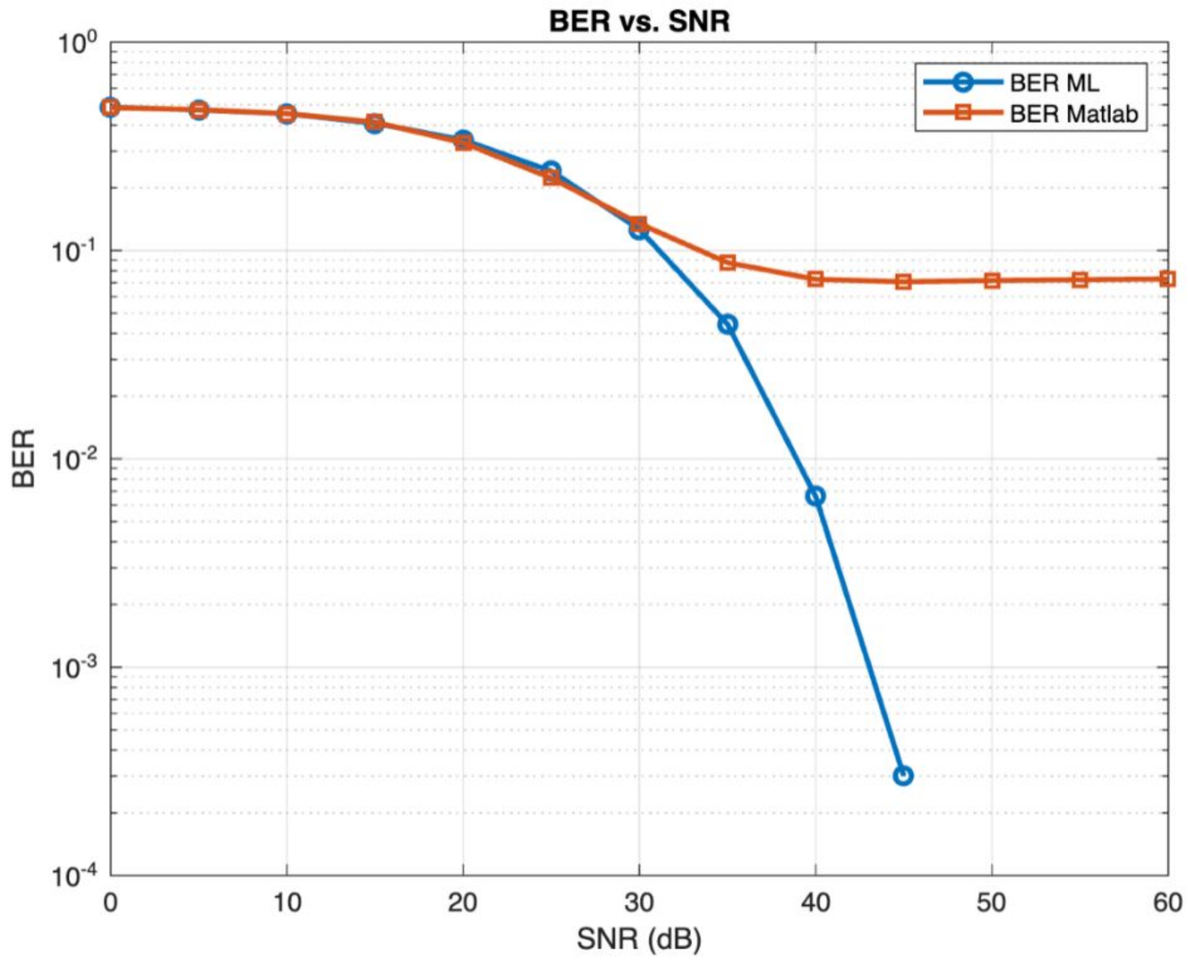
Results and Conclusion



- SNR vs BER at Bandwidth of 7MHz from MATLAB due to non-linearity

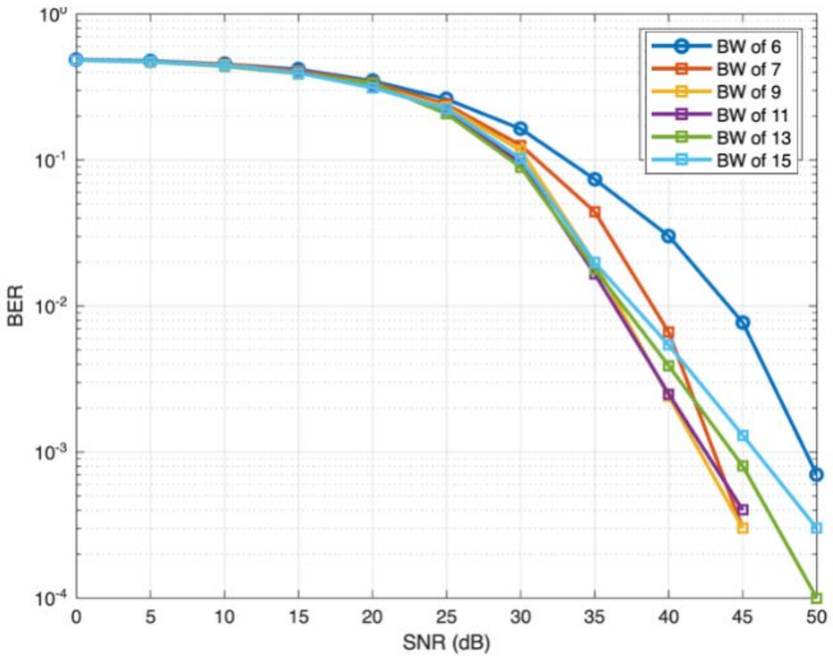


- SNR vs BER at Bandwidth of 7MHz after using ML model

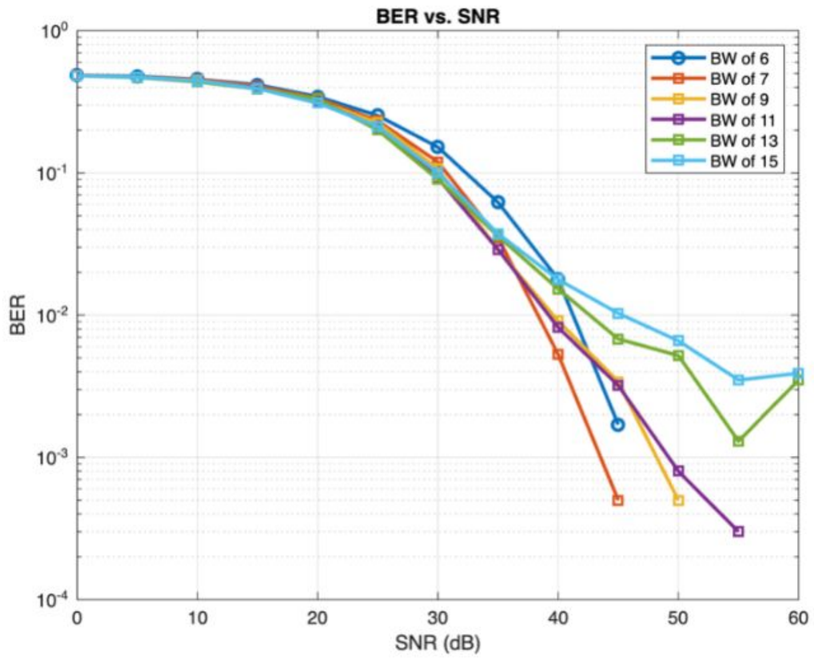


- SNR vs BER at Bandwidth curves before and after mitigating non-linearity effect

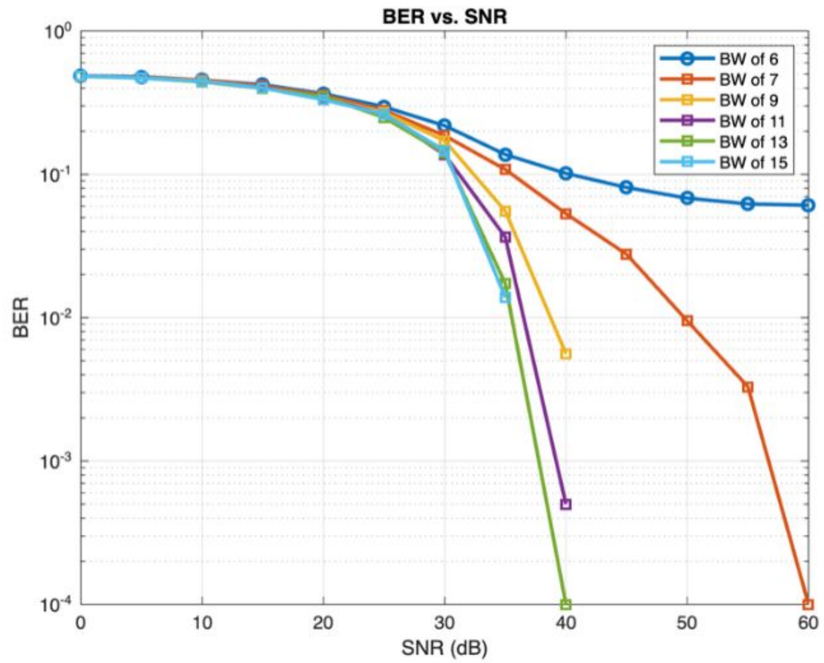
- Training of model is important step.If we train at high Bandwidth with less non-linearity then model might not perform well for less Bandwidth.So we need to train at optimal Bandwidth so that it performs well for all Bandwidth around so as SNR.



- Trained at 7MHz and 44 SNR



- Trained at 6MHz and 44 SNR



- Trained at 11MHz and 44 SNR

Conclusion And Future Work

- VLC is a promising technology, but LED non-linearity and limited bandwidth pose challenges.
- Machine learning, specifically ANN, can effectively mitigate non-linearity effects.
- The BER vs SNR curves clearly show the improvement in BER after applying the ANN model, particularly at challenging bandwidths by testing at 7MHz.
- Results show significant decrease in BER after applying the model.
- In conclusion, applying the ANN model significantly improves the performance of the VLC system, leading to a more reliable communication link with lower BER under various operating conditions.
- Further optimization of ML models.
- Extension to testing with hardware data.

References

- B. Lin, Q. Lai, Z. Ghassemlooy and X. Tang, "A Machine Learning Based Signal Demodulator in NOMA-VLC," in Journal of Lightwave Technology, vol. 39, no. 10, pp. 3081-3087, 15 May15, 2021, doi: 10.1109/JLT.2021.3058591.

- R. N. Toledo, C. Akamine, F. Jerji and L. A. Silva, "M-QAM Demodulation based on Machine Learning," 2020 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), Paris, France, 2020, pp. 1-6, doi: 10.1109/BMSB49480.2020.9379442.

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Thank You