BTP REPORT
MID SEM
EVALUATION

Title of Project:

Non- Linearity Mitigation in VLC Using Machine Learning

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Contents:

Aim of the project:

The aim of the project is to develop and implement an Artificial Neural Network (ANN) model to mitigate the effects of non-linearity in Visible Light Communication (VLC) systems, thereby improving data transmission reliability and reducing Bit Error Rate (BER). The project aims to leverage machine learning techniques to enhance the performance of VLC systems under different bandwidth and Signal-to-Noise Ratio (SNR) conditions, ultimately ensuring efficient and secure communication.

Introduction to Visible Light Communication(VLC):

The visible light communication (VLC) refers to communication technology which utilizes the visible light source as signal transmitter, air as transmission medium and photodiode as signal receiving component.VLC is a subset of optical wireless communications technologies. Visible light is only a small portion of the electromagnetic spectrum. The technology uses LEDs to transmit signals up to 500 Mb/s over short distances.The basic architecture of VLC consists of a light source (LED or laser diode), modulation of light intensity to transmit data, and reception using a photodiode that converts the received signal into a readable format.

Advantages of VLC:

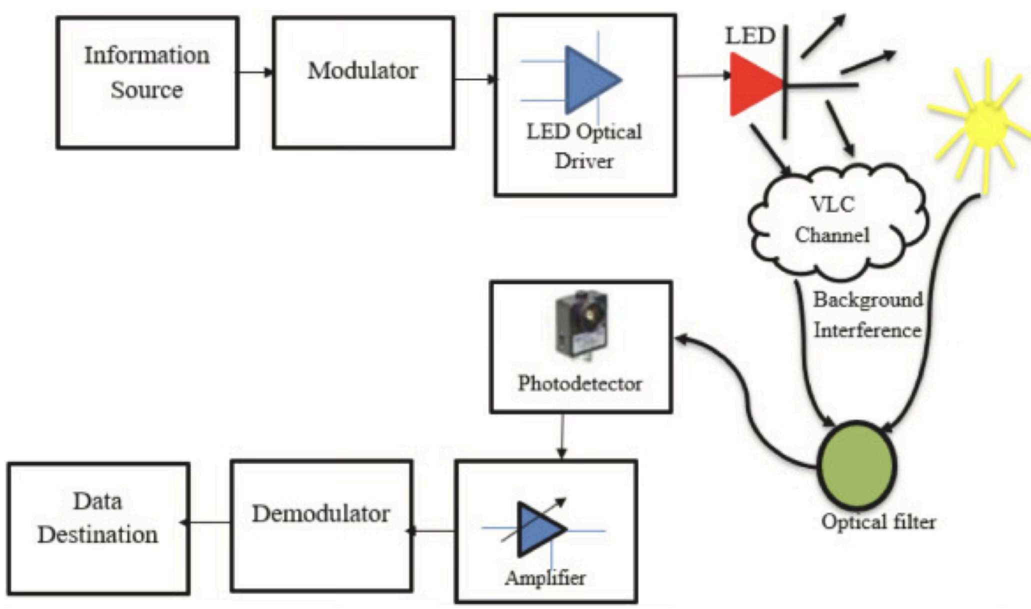
- VLC can achieve very high data rates, as visible light has a wider bandwidth compared to radio frequencies, allowing for faster communication.
- VLC uses visible light, which does not interfere with radio signals, making it ideal for environments sensitive to electromagnetic interference, such as hospitals and airplanes.
- VLC signals are confined within the line of sight, which limits eavesdropping risks and increases data security, as the communication cannot penetrate walls.
- VLC can simultaneously provide illumination and data communication, utilizing existing lighting infrastructure like LEDs, making it cost-effective and energy-efficient.

• Unlike radio frequencies, which require licenses, the visible light spectrum is unlicensed and widely available, avoiding the issues of spectrum congestion.

• **Indoor Positioning**: VLC can be used for accurate indoor positioning providing location-based services.

• **Internet Access**: VLC can provide internet access in areas where traditional radio frequency (RF) communication is limited.

Basic Architecture of VLC:



Transmitter:

Light Source (LED): The primary element of the transmitter is a Light Emitting Diode (LED) that acts as the light source. LEDs are modulated at high speeds to transmit data in the form of light signals.

Modulator: The data to be transmitted is converted into a suitable format for LED modulation. The modulator takes binary data and modulates the light intensity accordingly

Propagation Medium:
The medium for communication is visible light, which travels through free space. VLC signals propagate through a line-of-sight path.

Receiver:
Photodetector (Photodiode): The receiver uses a photodetector, typically a photodiode, to detect the light signals transmitted by the LED. The photodiode converts the received light into electrical signals.
Amplifier: The output from the photodetector is usually weak and needs to be amplified. An amplifier boosts the electrical signal for further processing.
Demodulator: The amplified signal is demodulated to recover the original data. The demodulator processes the changes in light intensity and translates them back into digital information.

LED and its characteristics:

Light Emitting Diode (LED) is a semiconductor device that emits light when an electric current passes through it. LEDs are widely used in Visible Light Communication (VLC) due to their efficiency, fast switching capabilities, and ability to modulate light intensity to transmit data.

High Modulation Speed:

- LEDs can be switched on and off rapidly, which is essential for VLC systems where the data is transmitted by modulating the intensity of light. This high modulation speed makes LEDs suitable for high-speed communication.

Brightness and Intensity Control:

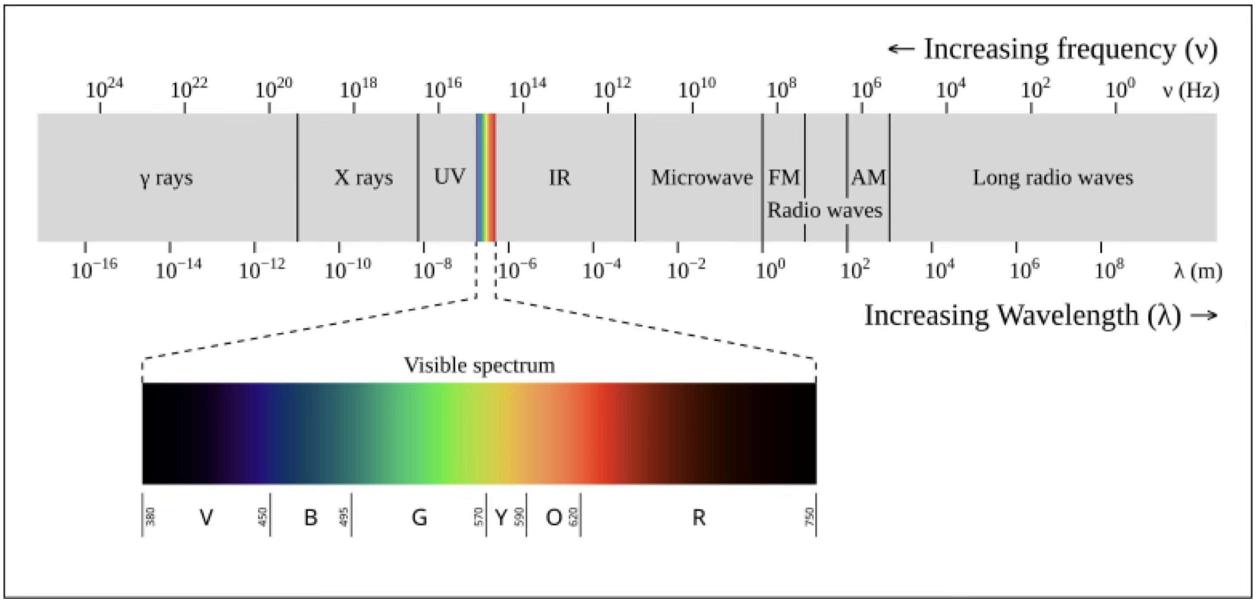
- The brightness of an LED can be easily controlled by adjusting the input current, allowing precise modulation of light intensity for data transmission. This characteristic is critical for encoding data in VLC.

Low Power Consumption:

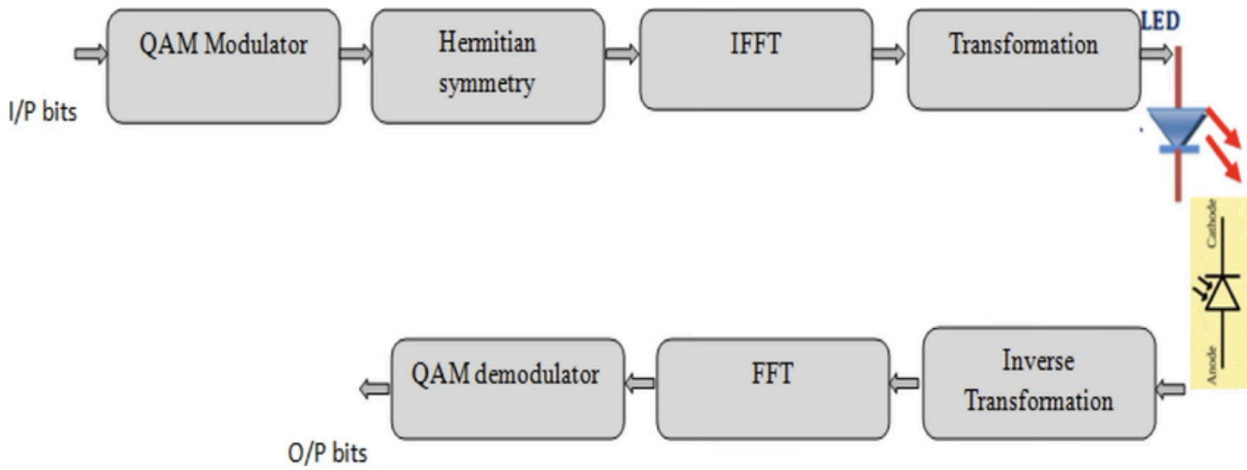
- LEDs consume less power compared to other light sources, making them energy-efficient. This is particularly useful in VLC, where continuous transmission is needed, and power efficiency is critical.

Bandwidth Limitation:

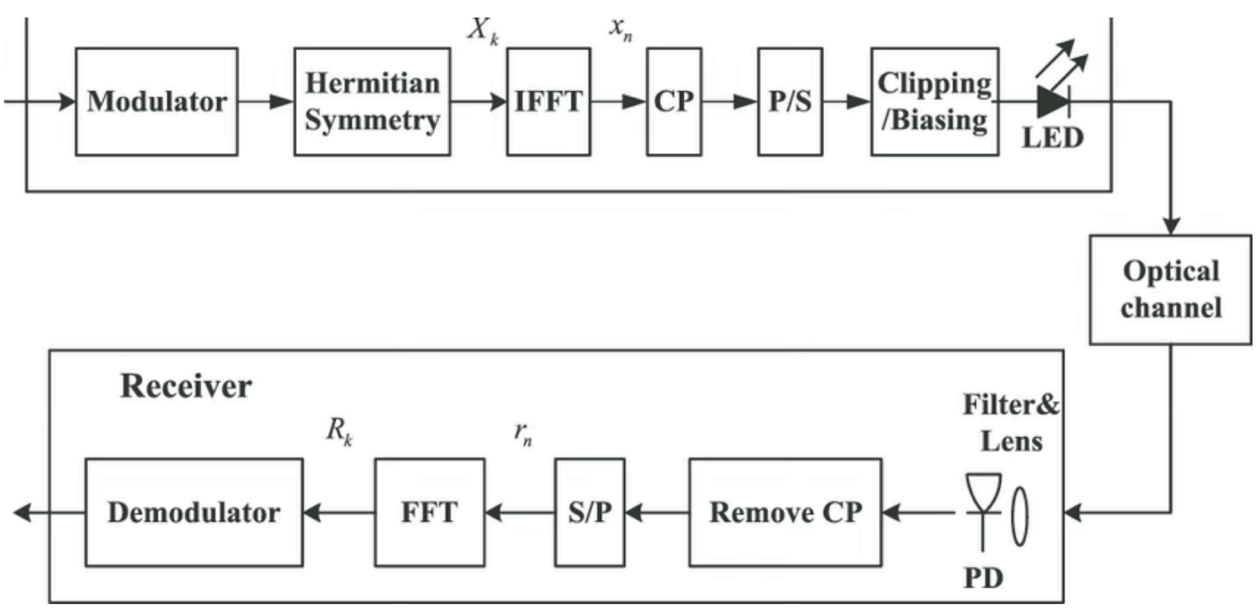
- The bandwidth of LEDs is determined by their switching speed. Although LEDs are much faster than traditional lighting sources, they have limitations in bandwidth, which can affect the data rates achievable in VLC. Techniques like pre-equalization and machine learning are used to mitigate these effects.



QPSK/QAM Signal Transmission using LED and OFDM in VLC:



Orthogonal frequency division multiplexing (OFDM) is used for a number of reasons.
Bandwidth efficiency: OFDM can efficiently use the bandwidth of LEDs.
visible light communication (VLC) systems for a
Reduced inter-symbol interference: OFDM can reduce the effects of inter-symbol interference (ISI).



The VLC system begins with the digital data stream (e.g., binary data: 0s and 1s) that needs to be transmitted.Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM) are common digital modulation techniques used in VLC to encode data.In QPSK, data is encoded into four distinct phase shifts (0°, 90°, 180°, and 270°), allowing 2 bits per symbol.In 16-QAM or 64-QAM, data is encoded by combining both amplitude and phase information, allowing higher data rates (4 or 6 bits per symbol).The modulated signal is now represented by symbols in the complex plane (I/Q components), ready for transmission.After modulation, the signal undergoes Hermitian symmetry. This step is crucial for ensuring that the IFFT process will generate a real-valued output, which is necessary for transmitting over the LED.

The IFFT converts the frequency domain signals into the time domain. This step is essential in OFDM as it allows the simultaneous transmission of multiple subcarriers, each carrying a portion of the data.A cyclic prefix is added to the signal to combat inter-symbol interference (ISI) caused by multipath propagation. This involves appending a copy of the end of the signal to the beginning, which helps preserve the integrity of the signal during transmission.

The modulated light signal is transmitted using the LED. The LED emits light based on the electrical signal's intensity, which is modulated to represent the original data.

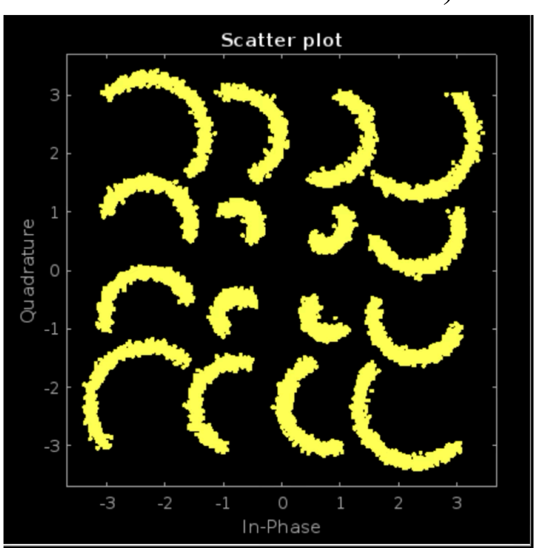
At the receiving end, a photodetector captures the light signal emitted by the LED. The PD converts the received optical signal back into an electrical signal.The cyclic prefix added earlier is removed to recover the original time-domain signal, preparing it for further processing.The FFT converts the time-domain signal back into the frequency domain, allowing the system to analyze the subcarriers for data recovery.The final step involves demodulating a signal using the same modulation technique (QPSK/QAM) that was used at the transmitter. This retrieves the original data bits from the modulated signal.

Disadvantages of LED as Transmitter

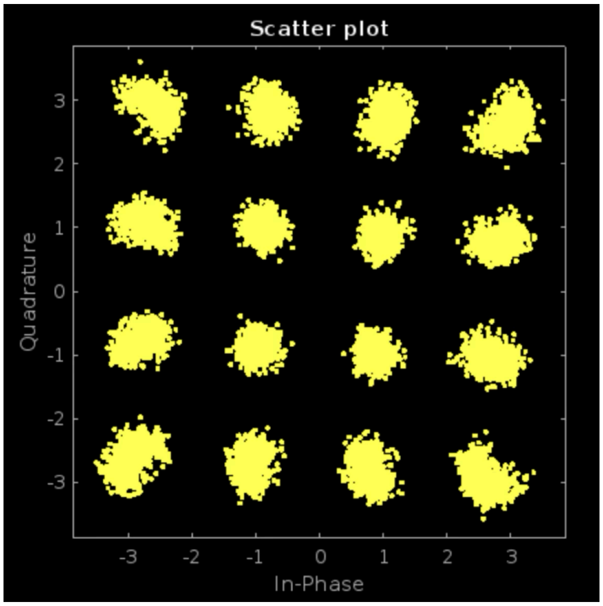
• LEDs have a limited bandwidth for modulating signals,usually in the range of a few MHz.

• LEDs exhibit a nonlinear current-voltage (I-V) curve.This nonlinearity causes signal distortion.
• LEDs have low optical power output.This limits the communication range and affects the signal-to-noise ratio(SNR) at the receiver
• 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 system's overall performance, particularly in terms of data rate, 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. This results in significant signal distortion for modulation schemes like OFDM.
•Limited modulation bandwidth directly restricts the data rate that can be transmitted through VLC systems.
•High-frequency components of the modulated signal (e.g.,components beyond the LED's modulation bandwidth) are severely attenuated or completely filtered out.



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



•Constellation of received data at 11MHz Bandwidth and SNR 44

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

Deep Learning Model for Nonlinearity Mitigation:

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 nonlinearity induced by limited LED bandwidth in Visible Light Communication (VLC) systems.A Deep Learning Model for Nonlinearity Mitigation in communication systems, particularly in Visible Light Communication (VLC) or Optical Wireless Communication (OWC), can enhance signal integrity and improve data transmission efficiency.

Model Architecture:

Artificial Neural Network (ANN) Architecture

We employed a Multi-Layer Perceptron (MLP), a neural network that consists of multiple layers of neurons. The MLP is designed to model the complex relationship between the nonlinear received signal and the desired bits.So it should be trained at optimal bandwidth and Signal to Noise Ratio(SNR) to achieve good results for all Bandwidth and SNR.

Input Layer:

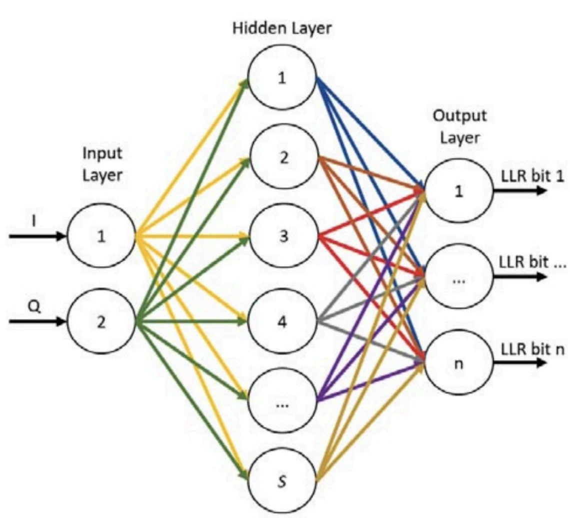
The ANN takes the received serial data as input, which consists of complex numbers.So in preprocessing we split complex numbers into real and complex part.Thus this is 2 input models.Normalization is applied to the received signal as a preprocessing step to generalize the model.This enables the model to be tested on signals with any power level without the need to retrain the model.

Hidden Layers:

The ANN contains two hidden layers with 64,16 neurons in the first and second layer.Each neuron applies a nonlinear activation function (ReLU) which allows the model to learn complex mappings from the distorted signal to the actual bits.

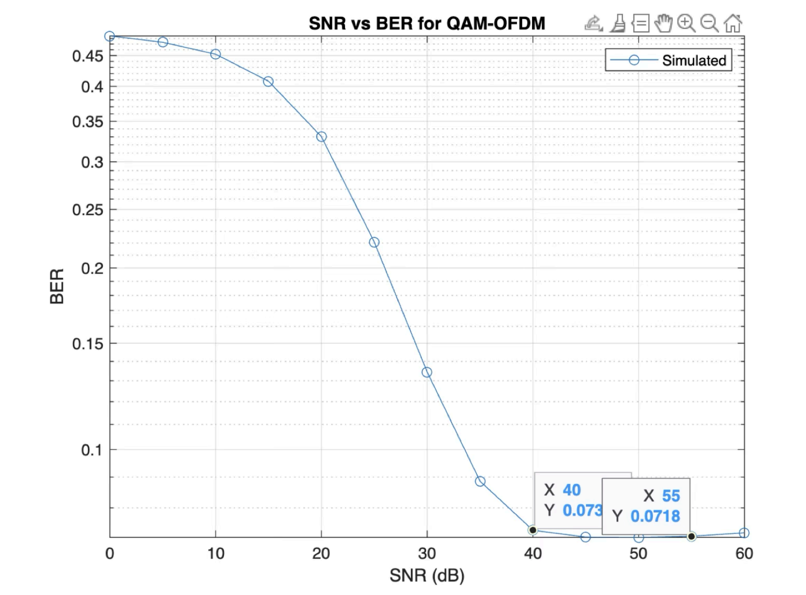
Output Layer:

The output layer generates the bits. These bits are the model's prediction of what the received bits should actually be where non-linearity has been mitigated.Bit error ratio(BER) is calculated by comparing predicted bit sequence to actual bit sequence.

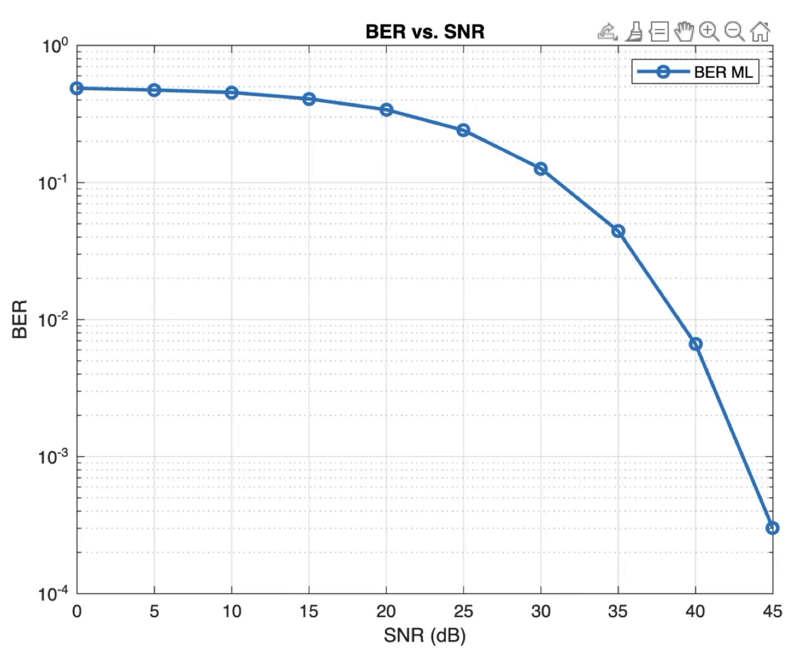


RESULTS AND CONCLUSION:

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



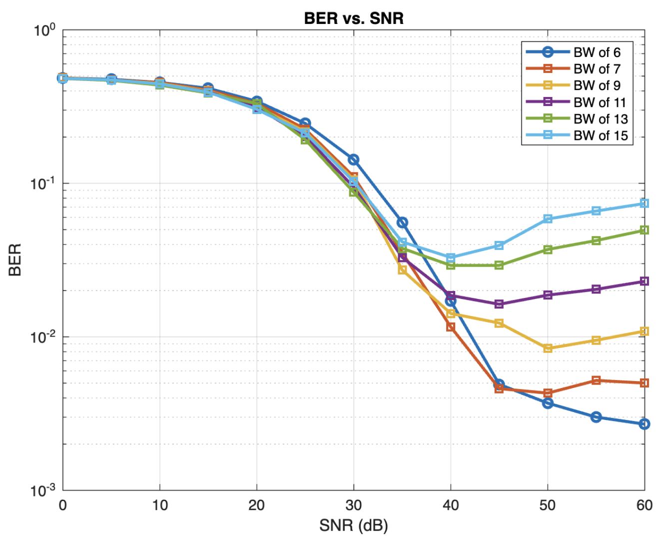
SNR vs BER at Bandwidth of 7MHz after using ML model



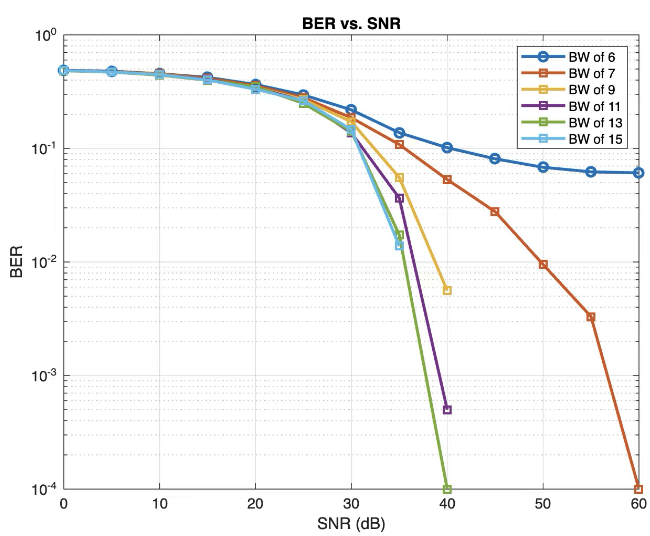
• Training of model is an important step.If we train at high Bandwidth with less non-linearity then model might not perform well for less Bandwidth.So we need to train at optimal Bandwidth so that it performs well for all Bandwidth around so as SNR.

Results for training at different Bandwidth and SNR:

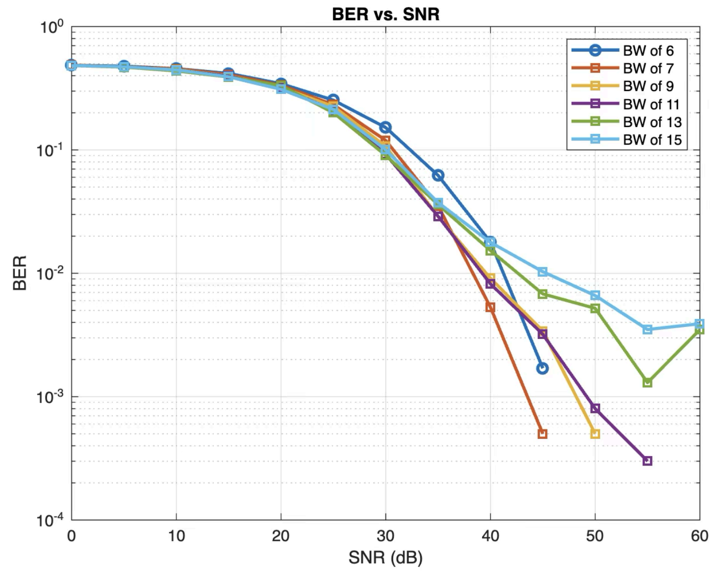
Trained at 7MHz and 32 SNR and tested with BW= 6MHz, 7MHz, 9MHz, 11MHz, 13MHz, 15MHz and SNR=[0:5:60]



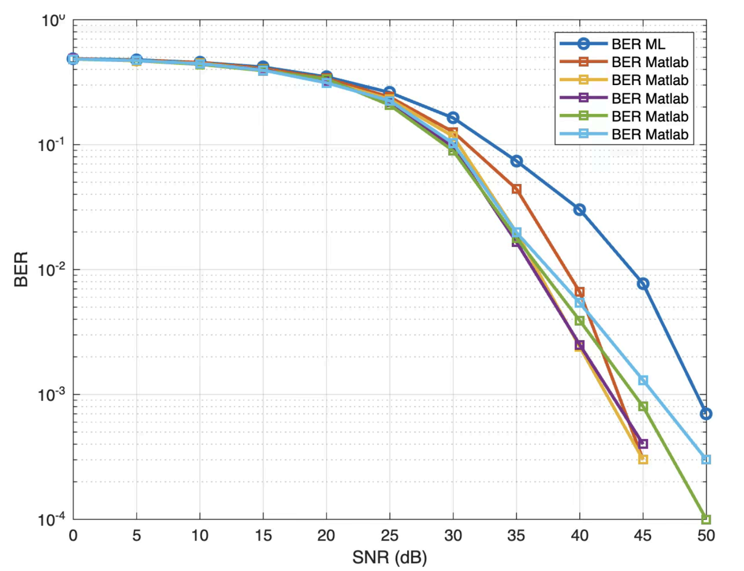
Trained at 11MHz and 44 SNR



Trained at 6MHz and 44 SNR



Trained at 7MHz and 44 SNR



CONCLUSION

- 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 and 44 SNR.
- 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.

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.